DOCUMENT RESUME

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IDENTIFIERS	*Drainage; Military Curriculum Project

ABSTRACT

This individualized, self-paced course for independent study in water drainage was adapted from military curriculum materials for use in vocational education. The course provides basic information for the design of simple drainage structures for roads and airfields. Some job skills included are designing and constructing ditches and culverts; designing subsurface drainage facilities; designing and using ponding areas; and designing check dams and drop inlets. The course consists of five lessons, each containing a lesson objective, readings, and review exercises. The course can be used as a sub-unit in environmental control, construction, or some types of agriculture courses. Each lesson has an objective, a coded text, exercises, and answers keyed to the text for student self-evaluation. A course examination of 50 multiple-choice questions is provided, but no answers are available. Supplementary charts and graphs are provided. (KC)

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MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

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Military Curriculum Materials
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The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

Agriculture
Aviation
Building & Construction Trades
Clerical Occupations
Communications
Drafting
Electronics
Engine Mechanics
Food Service
Health
Heating & Air Conditioning
Machine Shop
Management & Supervision
Meteorology & Navigation
Photography
Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

NORTHEAST
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

NORTHWEST
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0879

SOUTHEAST
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

WESTERN
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

DRAINAGE

Correspondence Course 3-5

Developed by:

United States Army

Development and Review Dates

Unknown

Occupational Area:

Building and Construction

Cost: $3.50

Print Pages: 173

Availability:
Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Suggested Background:

Basic math skills plus algebra, and chart reading skills

Target Audiences:

Grades 10-adult

Organization of Materials:

Lesson objectives, text readings, review exercises, answers, supplementary charts and graphs, and course examination

Type of Instruction:

Individualized and self-paced

Type of Materials:			**No. of Pages:**	**Average Completion Time:**
Drainage				
Lesson 1	–	Basic Drainage Principles	12	Flexible
Lesson 2	–	Surface Runoff (Hasty and Rational Methods)	36	Flexible
Lesson 2A	–	Surface Runoff (Talbot's and OCE Methods)	22	Flexible
Lesson 3	–	Design of Ditches and Culverts	9	Flexible
Lesson 4	–	Drainage Construction, Check Dams, Drop Inlets, Culverts and Ponding	27	Flexible
Lesson 5	–	Subsurface Drainage	12	Flexible
Examination			10	

Supplementary Materials Required:

Annex A-1 through A-6 and charts 1-3 provided	23

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Course Description

This course provides basic information for the design of simple drainage structures for roads and airfields. Some job skills included are:

- Design and construct ditches and culverts
- Design subsurface drainage facilities
- Design and use ponding areas
- Design check dams and drop inlets

This course consists of five lessons each containing a lesson objective, readings, and review exercises on the following topics:

Lesson 1 – *Basic Drainage Principles* covers the importance of drainage, types and functions of drainage, structures for surface drainage, structures for subsurface drainage, temporary drainage during construction, drainage maintenance, road drainage, airfield drainage, preliminary considerations for drainage design, data required, reconnaisance, general procedure in drainage design, design storm, grading, soil characteristics, frost action, uniform heave, differential heave, thawing, and sources of frost-action water.

Lesson 2 – *Surface Runoff (Hasty and Rational Methods)* is an introduction to runoff and describes the procedures for using the hasty and rational methods of calculating runoff.

Lesson 2A – *Surface Runoff (Talbot's and OCE Methods)* provides the formula for using the Talbot and OCE Methods along with example problems.

Lesson 3 – *Design of Ditches and Culverts* covers Manning's Formula for figuring design, construction equipment considerations, culvert design, size of pipe, flow and velocity.

Lesson 4 – *Drainage Construction, Check Dams, Drop Inlets, Culverts, and Ponding* is concerned with excavation of ditches with equipment, side ditches, errosion control, check dams, drop inlets, length and strength of culverts, strutting nestable corrugated metal pipe (CMP), headwalls and wingwalls, reasons for ponding, ponding design assumptions, ponding specifications, volume, runoff curves, analysis of cumulative runoff curve, culvert types, culvert hydraulic-design principles, and culvert design procedures.

Lesson 5 – *Subsurface Drainage* covers subsurface-drainage criteria, drainage techniques, pipe laying criteria, vertical wells, filter materials, preventing failures, and examples and steps in filter design.

This course is designed for student self-study and can be used as a sub-unit in environmental control, construction, or some types of agriculture courses. Each lesson has an objective, a coded text, exercises, and answers keyed to the text for student self-evaluation. A course examination of fifty multiple-choice questions is provided, but no answers are available. Supplementary charts and graphs are provided.

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ENGINEER 3
SUBCOURSE 359-3

DRAINAGE

CORRESPONDENCE COURSE PROGRAM
U. S. ARMY ENGINEER SCHOOL
FORT BELVOIR, VIRGINIA

3-5

This print includes solution Change 1, Dated 31 July 74

EDITION 3 (JULY 1973)

INTRODUCTION

More roads and airfields will be required by our Armed Forces in future wars than were required previously. The enemy's potential use of mass-destruction weapons will require a greater dispersion of our troops and equipment both in width and depth. A vast network of roads and airfields will be required to support these dispersed forces and to reassemble them for concerted offensive action.

Heavier aircraft and ground weapons will require the construction of stronger roads and airfields than were needed in previous wars.

A major factor in constructing and maintaining "combat-ready" roads, airfields, and other installations is the control of surface and subsurface water. It has been said that a good road requires a tight roof and a dry cellar. Water leaking through the surface of a road or airfield can weaken these structures from the top down. Failures from this source may be eliminated by adequate crown and/or by good wearing courses or pavements. But even when a watertight surface is provided, subsurface water may enter the foundation material and produce failure from the bottom. Foundation failures may be prevented by the proper use of materials and by the interception, collection, and disposal of the undesired water.

This course covers the design of simple drainage structures for roads and airfields. It will teach you to use rainfall data in selecting a design storm, to design and construct ditches and culverts, to design subsurface drainage facilities, to design and use ponding areas, and to design check dams and drop inlets. The subcourse consists of six lessons and an examination as follows:

Lesson 1. Basic Drainage Principles.
2. Surface Runoff (Hasty and Rational Methods).
2A. Surface Runoff (Talbot's and OCE Methods).
3. Design of Ditches and Culverts.
4. Drainage Construction, Check Dams, Drop Inlets, Culverts, and Ponding.
5. Subsurface Drainage.

Examination.

Eighteen credit hours are allowed for the subcourse.

You will not be limited as to the number of hours you may spend on the subcourse, any lesson, or the examination.

Materials furnished:

Annex A-1 through A-6—tables and graphs frequently used are separately bound for your convenience.

Charts 1, 2, and 3.

The format of this subcourse has been changed to facilitate student self-pacing and to eliminate the necessity of submitting to the USAES each lesson exercise for grading. Each lesson in this subcourse is followed by a number of questions and exercises designed for a review of that lesson. After completing study of the lesson, the student should answer these questions in the space provided below each, then turn to the back of the subcourse booklet where the correct answers have been included. A comparison of the student answers with those given in the back of the subcourse will indicate the student's knowl-

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edge and understanding of the material presented. When you have completed all lessons to your satisfaction, complete and forward the examination card which you will find in your subcourse packet.

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LESSON 1

BASIC DRAINAGE PRINCIPLES

CREDIT HOURS	2
TEXT ASSIGNMENT	Attached memorandum.
MATERIALS REQUIRED	None.
LESSON OBJECTIVE	To teach you the importance of adequate drainage, theater-of-operations drainage considerations, and how to use rainfall data.
SUGGESTIONS	Read the attached memorandum through rapidly to obtain a knowledge of its scope. Then read it through carefully, underlining the important points and objectives. Read the review questions at the end of the lesson. Study the lesson, searching for answers to the review questions, and write your answers in the spaces provided. Finally, check your answers with the answers given for this lesson at the back of this booklet. Review as necessary.

ATTACHED MEMORANDUM

1-1. IMPORTANCE OF DRAINAGE

Drainage is an important consideration in the planning, design, and construction of military roads and airfields, both as to construction and use. The entire serviceability of the road depends on the adequacy of the drainage system. The washout of a single culvert may close the road to traffic at a crucial time. The development of a soft spot may lead to rutting and displacement and to eventual closing of the road for repairs. Properly designed and constructed drainage systems are equally vital to the functioning of an airfield. It is most important that adequate drainage facilities be constructed to remove effectively any surface water from the runways and taxiways. One severe accident resulting from inadequate drainage may offset any difference between the cost of reasonably adequate and less-than-adequate facilities. Adequate drainage, including the use of pumping facilities of even a temporary nature, is of primary importance during the period of construction. Inadequate drainage results in high maintenance of construction equipment and seriously interferes with the efficiency of both men and equipment. The first construction work on any project should provide drainage for the work to follow. As construction progresses, every effort should be made to complete the drainage system as planned, in order to avoid any damage which

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might be caused by accumulations of mud, water, ice, and debris. Flooding caused by inadequate drainage may lead to failure of road and airfield surfaces. Engineer officers and noncommissioned officers should be fully aware of the function of drainage, including adequate drainage during construction, and the proper methods of providing it. The importance of drainage in road and airfield design and construction cannot be overemphasized.

1-2. TYPES AND FUNCTIONS OF DRAINAGE

All drainage can be classified as surface or subsurface. Classification depends on whether the water is on or below the surface of the ground at the point where it is first intercepted or collected for disposal.

a. **Surface drainage.** Surface drainage provides for the collection and removal of water from the surface of roads, runways. taxiways, and hardstands. This is important because water on the surface interferes with traffic, may cause erosion, and, if allowed to infiltrate, can cause injury to the subgrade. Surface drainage also provides for the interception, collection, and removal of surface water flowing toward road and airfield surfaces from adjacent areas.

b. **Subsurface drainage.** Subsurface drainage is similar in some respects to surface drainage. Impervious strata may form well-defined channels and reservoirs for subsurface water. Water is present under the surface because of infiltration of surface water. Surface water seeps down through open or unsealed surfaces, or laterally on top of impervious soil or rock layers. Accordingly, properly designed and maintained surface-drainage systems should reduce the need for special facilities for control and disposal of ground water. Ground water may pond above impervious strata to form a subsurface lake (which is often called a perched water table). Subsurface drainage is provided to intercept, collect, and remove any flow of ground water into the subgrade; to lower high water tables; to drain water pockets or perched water tables; or for any combination of these purposes. The employment of subsurface drainage to prevent frost action damage is discussed later in this lesson.

1-3. STRUCTURES FOR SURFACE DRAINAGE

a. **Crown or transverse slopes.** Surface water is removed from road and airfield pavements or wearing courses by providing adequate crown or transverse slopes. Paragraphs 1-7 and 1-8 describe crown specifications for roads and airfields respectively.

b. **Open channels other than ditches.**

(1) **Gutters.** Gutters, or combination curbs and gutters, are used to collect and control surface runoff where open ditches would be hazardous or impractical. They are most commonly employed along streets in densely settled areas, and along roads through heavy cuts where the width of the roadway is limited.

(2) **Dikes.** Dikes or intercepting embankments are used along shoulders on high fills, or along the tops of cut slopes, to collect runoff. Such runoff may be directed into flumes or into natural drainage courses to prevent the erosion of unstable slopes. Flumes are installed on the surface of steep slopes to carry the accumulation of surface water to open ditches or to natural drainage channels.

c. **Ditches.** Ditches, alone or in combination with natural watercourses, provide the simplest as well as the cheapest and most efficient method for handling surface water. The detailed design of ditches is covered in lesson 3. The following subparagraphs discuss some factors to guide you in the use and location of ditches, as illustrated in figure 1-1.

(1) **Diversion ditches.** At every opportunity drainage water should be diverted or discharged from collecting channels or side ditches into natural or artificial channels and carried away from the site. This diversion keeps side ditches and channels reasonable in size, and reduces the seepage from the ditches into the subgrade.

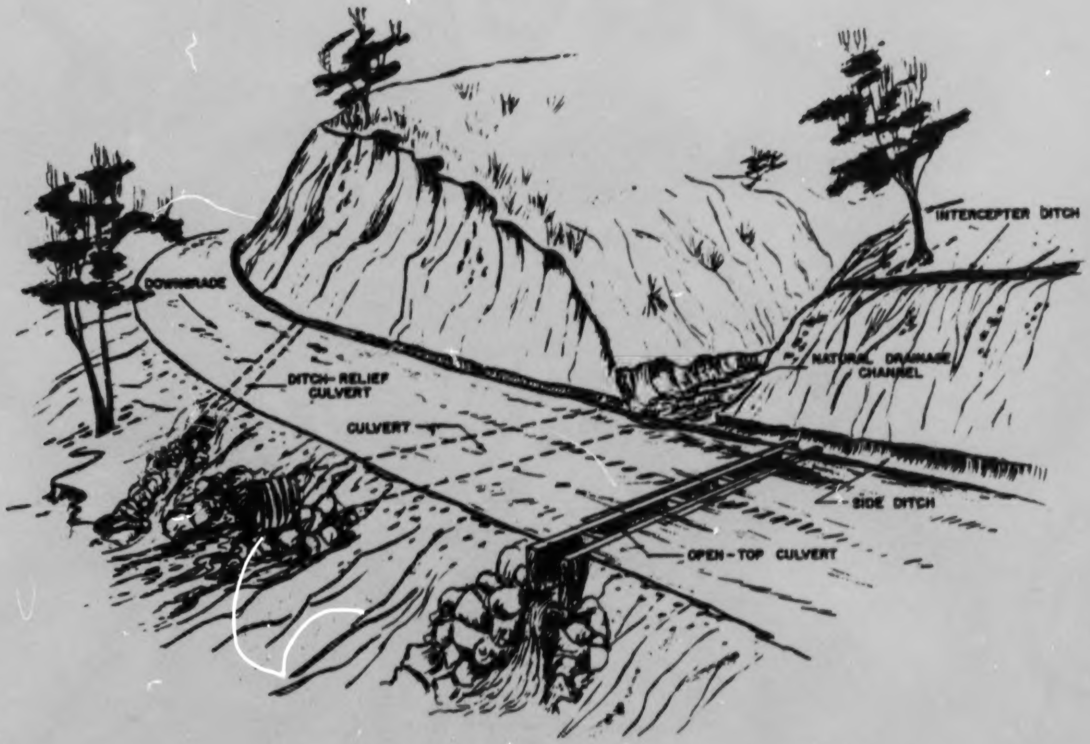

Figure 1-1. Structures for surface drainage.

(2) **Interception ditches.** Much of the surface water originating on adjacent areas which slope toward a construction site can be intercepted and carried off in interceptor ditches before it reaches the site. Intercepting the surface water reduces the volume of flow into drainage facilities within the operating areas and prevents drainage structures from reaching uneconomical sizes. Without interceptor ditches, all of the water from a hill would flow along the inside or cut-side ditch. The pipe necessary to provide for the gradual increase of flow would be excessive in size and very expensive.

(3) **Placing of ditches along fills.** In some cases, drainage ditches must be constructed parallel to the edge of a fill. When this is necessary, the ditch should be dug into the natural ground. The fill-ground-line intersection should not be used as the bottom of the ditch because surface water would tend to infiltrate and weaken the fill. A berm should be placed between the toe of the fill and the ditch when the fill is over 4 feet high. Figure 1-2 illustrates both the correct and the incorrect method for locating a ditch parallel to a fill.

d. **Storm drains.** In permanent construction, storm drains are frequently used because property values will not permit large surface ditches, particularly for disposal of collected runoff. Storm drains are seldom justified for theater-of-operations construction because it is more economical to use open ditches. When

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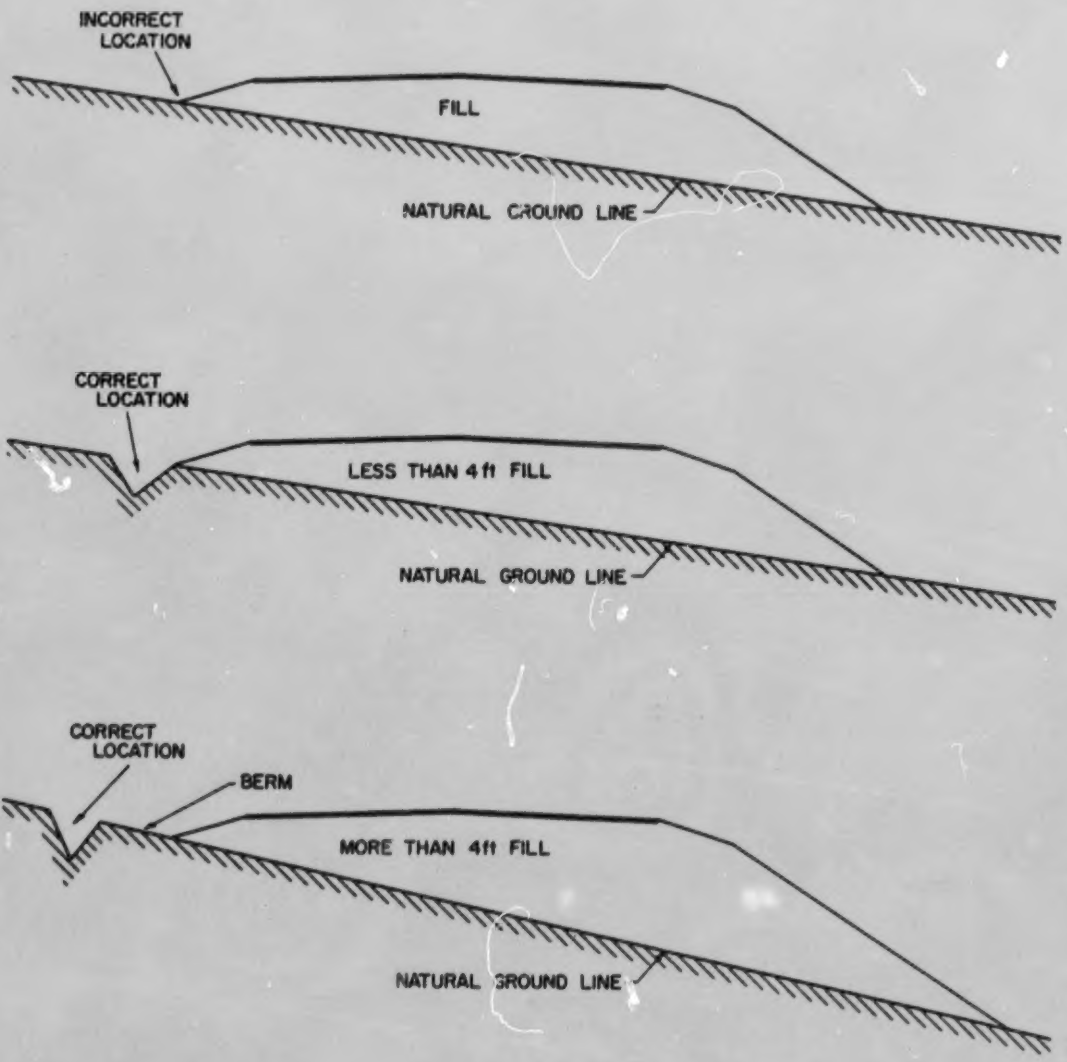
INCORRECT LOCATION
FILL
NATURAL GROUND LINE
CORRECT LOCATION
LESS THAN 4 ft FILL
NATURAL GROUND LINE
CORRECT LOCATION
BERM
MORE THAN 4 ft FILL
NATURAL GROUND LINE

Figure 1-2. Construction of ditches parallel to fills.

space is restricted, or the natural slope of the ground is unsuited for the use of open channels, it may be necessary to install storm drains to provide for the disposal of surface water. A storm-drainage system is very different from a sanitary layout. A sanitary system must gather all sewage into one collecting system and carry it to a treatment or disposal plant. Storm drains are best installed in small units, each unit draining a small area and carrying the water to the nearest watercourse.

e. **Culverts.** Culverts are used under roads, taxiways, and, occasionally, under runways, to carry water that cannot be diverted economically to natural drainage channels by other means. They differ from storm drains in that they generally conform to the grade and alinement of the open ditch, stream, or natural drainage course at inlet and outlet ends. Additional information about culverts and culvert design is contained in lessons 3 and 4.

1-4. STRUCTURES FOR SUBSURFACE DRAINAGE

In most cases, the presence of excess water in the subgrade or base course reduces the stability of the pavement foundation and increases damage from frost action. Subsurface drainage removes this excess water by lowering the water table, by accelerating water flow, by providing a ready outlet for slow-moving ground water, or by intercepting such water before it reaches the areas that it could damage. Open channels, subdrains, combination drains, and vertical wells are used to control ground water.

a. Open channels. Subsurface drainage may sometimes be accomplished by providing side ditches or making existing ditches deeper. Such ditches or open channels often lower the water to a safe level and also intercept seepage. Deep ditches are often impractical and are hazardous and should not be located adjacent to a roadway or runway. The ability of open channels to collect and remove subsurface water depends upon the nature of the subsurface soil, the location of the channel with respect to the pavement, and the availability of a suitable outlet for the water collected.

b. Subdrains. Subdrains (also referred to as subsurface drains, subgrade drains, and underdrains) are underground drainage lines or ducts used only to collect and dispose of ground water. Subdrains may be constructed of porous concrete, perforated clay pipe, or perforated corrugated metal pipe laid with closed joints, or unperforated concrete, clay or tile pipe, laid with open joints. These pipes should be enclosed in a layer of selected filter material. Blind drains constructed of crushed rock or gravel of desirable graduation, and drains improvised out of timber, are other methods employed for subsurface drainage. Subdrains made of pipe, as well as blind or French drains, should be provided with free-flowing outlets, and, insofar as is practicable, should be constructed to prevent backwater in the drain. A more complete discussion of subsurface drainage is given in lesson 5.

c. Combination drains. Underground drainage lines which combine subsurface and surface drainage are known as combined or combination drains. Combination drains usually consist of a subdrain modified to permit the entrance of surface water. This is accomplished by extending the filter material surrounding the drain to the ground surface, or near the surface, and covering with a pervious soil layer. The installation of combination drains should be avoided, when possible, since they allow infiltration of sediment and washing of soil from the trench sides into the system. This usually leads to more maintenance and repair work on the pavement adjacent to the drain, and will require the additional work of cleaning the drain pipe.

d. Vertical wells. Vertical wells are sometimes constructed to permit trapped subsurface water to pass through an impervious soil or rock layer to a lower, freely draining layer or soil. If drainage is obstructed, additional wells are driven, or the pocket is drained with a lateral subdrain system that is easily maintained. Vertical wells are often used in northern latitudes, where deep freezing is common, to permit fast runoff from melting snow to get through the frozen soil and reach a pervious stratum. The bottoms of these wells are treated with calcium chloride or a layer of hay to prevent freezing.

1-5. TEMPORARY DRAINAGE DURING CONSTRUCTION

Proper consideration of drainage during the construction period will frequently eliminate costly initial delays and future failures due to saturated subgrades. A careful consideration of the following items will aid in maintaining satisfactory drainage during the construction period.

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a. Diversion and outfall ditches. Drainage necessary at the site to eliminate water which would interfere with construction operations includes excavating diversion ditches to concentrate all surface water in natural channels, and building outfall ditches to drain low or swampy spots. Such work is an initial operation and may proceed at the same time as clearing and grubbing. Careful consideration should also be given to the drainage of all construction roads, equipment areas, borrow pits, and waste areas.

b. Use of existing ditches and drainage features. Maximum use of existing ditches and drainage features should be made. Where possible, grading operations should proceed downhill, both for economical grading and to utilize natural drainage to the greatest extent. Backfilling existing ditches and drainage channels should be so scheduled as to permit the longest possible use of these structures for temporary drainage.

c. The use of temporary crowning. It is necessary to maintain well-drained subgrades and base courses at every stage of construction to prevent detrimental saturation. When work is temporarily suspended a particular effort should be made to remove runoff from the site. Cut and fill sections must be crowned and high shoulders must be lowered.

d. Coordination of drainage plans. Construction drainage plans should be coordinated with the layout and design of final drainage facilities to insure maximum use of temporary drains in constructing permanent facilities.

1-6. DRAINAGE MAINTENANCE

The drainage system must be maintained so that it can function efficiently at all times. This goal can be obtained through adequate maintenance inspections of the structures, with careful attention to removal of debris and prevention of erosion. Periods of dry weather must be utilized in improving the drainage system and correcting and preventing drainage failures. Any deficiencies in the original drainage-systems layout must be corrected as they are discovered.

a. Surface drainage. Defective or inadequate drainage is responsible for many pavement failures and much deterioration. Ponding or delayed runoff of surface water allows seepage unless the surface is tightly sealed. Areas are marked where inspection after rains reveals ponding of surface water. Correction is made by filling or raising local depressions, by providing additional culvert capacity, and by providing outlets for water obstructed by high shoulders. Penetration of storm waters through pavement is controlled by sealing joints and cracks.

b. Ditches and drains. Drainage ditches must be kept clear of weeds, brush, sediment, and other accumulation of debris that obstruct the flow of water. Ditches are maintained as to line and grade, and sags and minor washouts are corrected as they occur. Unnecessary blading or cutting, which destroys natural ground cover, is avoided in cleaning and shaping. Dense sod is developed to stabilize open ditches. Where vegetation is not effective because of soil or moisture conditions, erosion may be corrected by lining the ditch with riprap or compacted bituminous mix. Clogged drains and culvert pipes are opened by cleaning out excess sediment. Culverts which have settled, heaved, or which have been pushed out of line are repaired or replaced.

c. Winter maintenance. Special attention must be given to drainage maintenance during thaws if there are accumulations of snow. Side ditches are cleared of snow, and channels are opened through snow accumulations on the shoulders to permit water to escape into the ditches. Every precaution is taken to prevent melt water from ponding on the runway, on the shoulders, or in side ditches. Culverts and drains are kept free of ice and snow.

1-7. SPECIAL CONSIDERATIONS FOR ROAD DRAINAGE

The basic objectives and requirements for surface and subsurface drainage are covered in previous paragraphs. A few additional considerations are presented here because of their particular application to road drainage.

a. Drainage of road surfaces. Surface water is removed from the roadbed to keep it from penetrating the surface and wetting the subgrade. Removal of this water is accomplished by the introduction of a crown or of a transverse slope across the entire roadbed width, or by superelevation on curves. The amount of slope provided by crowning generally depends upon the type of road surface. All smooth-surfaced roads are crowned between ¼ and ½ inch per foot. Gravel roads and other rough, untreated surfaces require a crown of ½ to ¾ inch per foot. In mountainous terrain, where sidehill cuts and fills are necessary, side sloping is frequently used instead of crowning. This is done in order to divert all surface water to the ditch on the inner, or cut, side of the road, and thus prevent erosion on the outer, or fill, side. Superelevation serves in place of crowning to take water from the surface of the road on curves. Open-top culverts constructed of logs, timber, or rocks may be used on steep grades where heavy flow is expected down the road surface. They are placed at an angle of about 60° to the centerline or 30° to the perpendicular of the road. See figures 1-3 and 1-4.

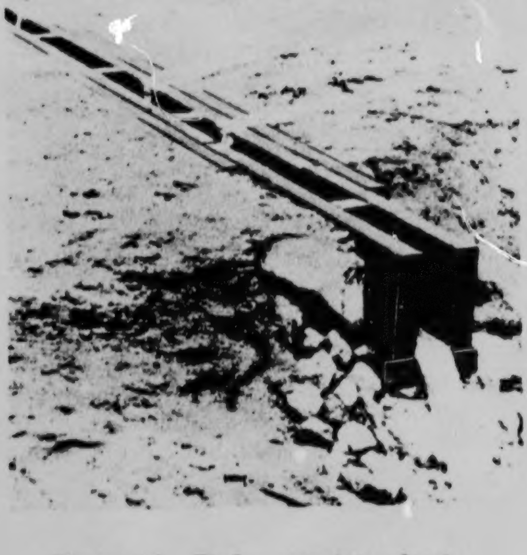


Figure 1-3. Timber open-top culvert.

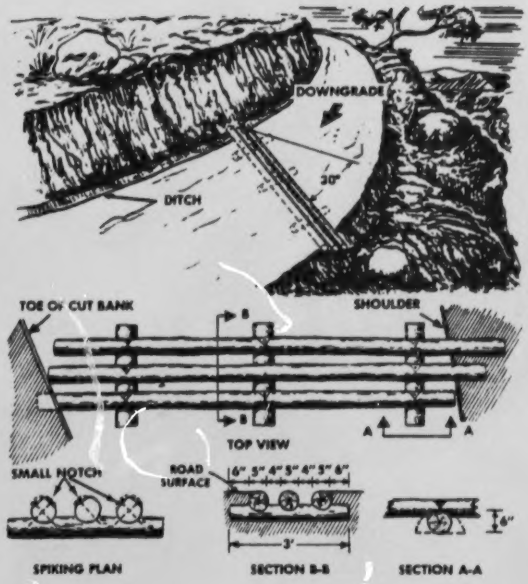


Figure 1-4. Log open-top culvert.

b. Side ditches. Water draining from the roadbed surface is collected into side ditches for disposal. These side ditches generally serve to collect water from a considerable area adjacent to the road. They should be large enough to accommodate the runoff both from the roadbed and adjacent areas. Side ditches are a potential danger to traffic. To reduce this danger to a minimum, the shoulders should be constructed as wide as is practicable, with a minimum width of 4 feet, and with a uniform slope toward the ditch. If possible, the required cross-sectional area should be obtained by constructing a broad, shallow trapezoidal ditch. This type of ditch has a large capacity. Its minimum depth below the edge of the shouder should be 1½ feet. The minimum practical trapezoidal section is 1½ feet deep and 2 feet wide at the bottom. Side slopes should not be greater than 1½ to 1 in cohesive soil, and 3 to 1 in sandy or loamy soils. When possible, ditches should be deep enough to lower the ground-water table under the road to below the subgrade elevation, and thus permit drainage of the subgrade by seepage into the ditch. Where it is economically possible to develop and maintain turfed drainage channels, the side slopes should not be steeper than 4 horizontal to 1 vertical to facilitate mowing and other operations incident to maintenance. Ditches with comparatively flat side slopes must be protected by rigid traffic control against indiscriminate crossing by vehicles.

c. **Ditch-relief culverts.** On sidehill cuts or wherever roads intercept surface water either in cut or fill, the water is drained to the fill side of the road by ditch-relief culverts. This is done to prevent ditches from reaching uneconomical sizes or dangerous depths and to prevent erosion and saturation of subgrades by the increasing volume of water. On 8 percent grades, ditch-relief culverts are spaced about 300 feet apart; on 5 percent grades, 500 feet apart. Earth ditch blocks or headwalls are used to prevent the water from flowing past the culvert. In deep cuts it may be cheaper and quicker to install culverts than to increase the width of the excavation to provide space for wide side ditches.

d. **Subsurface drainage.** Subsurface drainage is very rarely used in military roads except where it is expedient for special local conditions such as drainage base courses subject to excessive saturation, draining ground water encountered during construction, or draining craters or frost boils during repair and maintenance operations. An effective method to drain the base course is to cut trenches through the shoulder to the bottom of the base course at approximately 150-foot intervals on the low side of the subgrade, and backfill with pervious material. Where the longitudinal slope of the base is greater than its transverse slope, transverse ditches (approximately 1 foot in width and to a depth of 1 foot below the bottom of the base course) are excavated completely across the base course and through the low shoulder. The ditches are backfilled with pervious material. They should be placed at the low point of grades and at the meeting points of fill and cut.

1-8. SPECIAL CONSIDERATIONS FOR AIRFIELD DRAINAGE

Basic information applicable to drainage and drainage systems is contained in previous paragraphs. A few additional considerations are presented here because of their particular application to airfields.

a. **Drainage of runway and taxiway surfaces.** Provision must be made for positive disposal of surface water from runway and taxiway surfaces by shaping the cross section to shed water to the sides. The maximum permissible transverse slope for runways is normally 3 percent. For drainage purposes, a minimum longitudinal grade of 0.4 percent should be maintained. Maximum and minimum grades for runways and taxiways are given in TM 5-330 and in pertinent Air Force publications. Shallow V-ditches with side slopes of from 4:1 to 10:1 may be constructed, starting at the outer edge of the runway or taxiway shoulder. Deep ditches produce an operating hazard and, if used, must be located from about 100 to 175 feet from paved surfaces.

b. **Effects of drainage on general design.** Proper grading is the most important single factor contributing to the success of the drainage system, and the grading and drainage plans must be carefully coordinated. Although runways, taxiways, hardstands, and aprons must be laid out to conform to certain basic principles and specifications, care should be taken in determining the exact location of these structures so as to facilitate drainage as much as possible. Airfield layout should be planned to take full advantage of topography in draining the site, to utilize the existing natural drainage system, and to avoid small hard-to-drain areas. The exact location of the runway may be governed by soil conditions, since subsurface water and drainage characteristics of the soil may vary widely between alternative runway locations. The two drainage factors affecting the position of grade and centerlines are the shape and size of structures required in natural drainage channels crossing the runway or taxiway, and the height of the ground-water table. Raising the paving grade may be necessary to (1) obtain sufficient crown or transverse slope; (2) to provide a minimum of 1 foot between the ground-water table or capillary water and the bottom of the base course in soils where subgrade drainage is impractical; and (3) to maintain the required minimum cover above drainage structures. Drainage considerations, in conjunction with soil conditions, also determine whether or not the runway surface must be impervious.

c. Erosion control. Erosion control at an airfield site is not only required to keep the drainage system effective with a minimum of maintenance, but also to avoid possible hazards to operations because of dust. Seeding and planting open channels and dirt surfaces prevents erosion and increases stabilization. Erosion control in nonuse areas may frequently be accomplished by terracing, in conjunction with a well-developed turfing program. The terrace consists of a low, broad-based earth levee constructed approximately parallel to the ground contours, and designed to intercept overland flow before it can cause erosion, and to conduct it to a suitable discharge point. TM 5-330 discusses the design of terraces.

1-9. PRELIMINARY CONSIDERATIONS FOR DRAINAGE DESIGN

a. Objective. The drainage system must be designed to remove all surface water effectively from operating areas, to intercept and dispose of surface water from adjoining areas, and to intercept and remove detrimental ground water. The drainage system should be designed to meet operational requirements with the selected design storm to be dependent upon location, facility served, local conditions, and the like.

b. Type of installation. Consideration must be given to the proposed use of the road or airfield. If the road or airfield is to be used for only a short period of time, such as one or two weeks, hasty design procedures would probably be used. However, if improvement or expansion is anticipated after the original operational requirements are met, drainage should be designed so that any future construction does not overload ditches, culverts, and other drainage facilities. When all-weather operation is required, the drainage problems are more difficult than if the road or airfield is to be used only during certain periods.

c. Engineer resources. The availability of engineer resources is an important preliminary consideration. Heavy equipment, such as dozers, graders, scrapers, and power shovels, is commonly used on drainage projects. Where unskilled labor is available in large quantities, together with the necessary hand tools, much work can be done by hand. Provision must be made for the proper use of all available materials necessary for culverts, ditch lining, bridges, drains, and retaining walls.

1-10. BASIC INFORMATION AND DATA REQUIRED

Before any design can be undertaken, certain basic information must be available. The amount required, of course, varies with the complexity of the design.

a. Topographic data. The best available topographic map should be utilized for laying out drainage facilities because the topography greatly influences the rate of runoff, and largely determines the number and size of the drainage structures required to drain a given area. Contour maps or aerial photographs of the road or airfield site and the land adjacent to it should show all natural watercourses. If possible, contributing areas should be defined or their areas indicated on the largest-scale map that can be obtained.

b. Precipitation data. Because the maximum rate at which rain falls is one of the most important factors to be estimated as a basis for drainage design, all possible rainfall data, such as frequency, intensity, and duration of storms, should be considered to aid in the determination of this rate. Rates of precipitation vary considerably between different areas on the same continent (see fig 2-5, lesson 2, world isohyetal map); rainfall data for the locality being considered is of primary importance in designing a drainage system that will insure prompt removal of surface water and positive control of ground water. Ordinarily the most intense rainstorms that occur in a localized area are short, intense storms such as thunderstorms. It is common practice to design storm drains to provide for disposal of runoff from rainfall having certain average recurrence intervals or frequency of occurrence. The rainfall intensity corresponding to a particular frequency of occurrence varies appreciably with the duration of the rainfall, the average rate for a period of 5 minutes usually being several times higher than the average for a period of 1 hour. A study of rainfall intensity-frequency data for a large number of weather stations indicates that there are fairly consistent relationships between the average intensity of rainfall for a period of 1 hour and the average rates of comparable frequency for shorter intervals, regardless of the geographical location of the stations or frequency of 1-hour rainfall. Consequently standard curves may be developed to express the rainfall "intensity-duration" relationships with an accuracy satisfactory for road and airfield drainage problems (fig 1-5).

c. **Infiltration.** The term infiltration refers to the absorption of rainfall by the ground during a rain storm. The infiltration capacity, or ability of a soil to absorb precipitation, normally decreases as the duration of rainfall increases, until a fairly definite absorption rate is reached. Variations in the state of compaction, soil-moisture deficiencies at the beginning of rainfall, and the elevation of the ground-water table may greatly influence the infiltration capacity of a particular soil.

d. **Temperature and frost data.** Temperature and frost data, with particular attention to maximum depth of frost penetration, should be ascertained.

e. **Soil and ground-water data.** Soil and ground-water data should be obtained from a soil survey.

f. **Other data.** The necessary charts, graphs, and tables for the design of the various types and sizes of culvert construction materials should be procured.

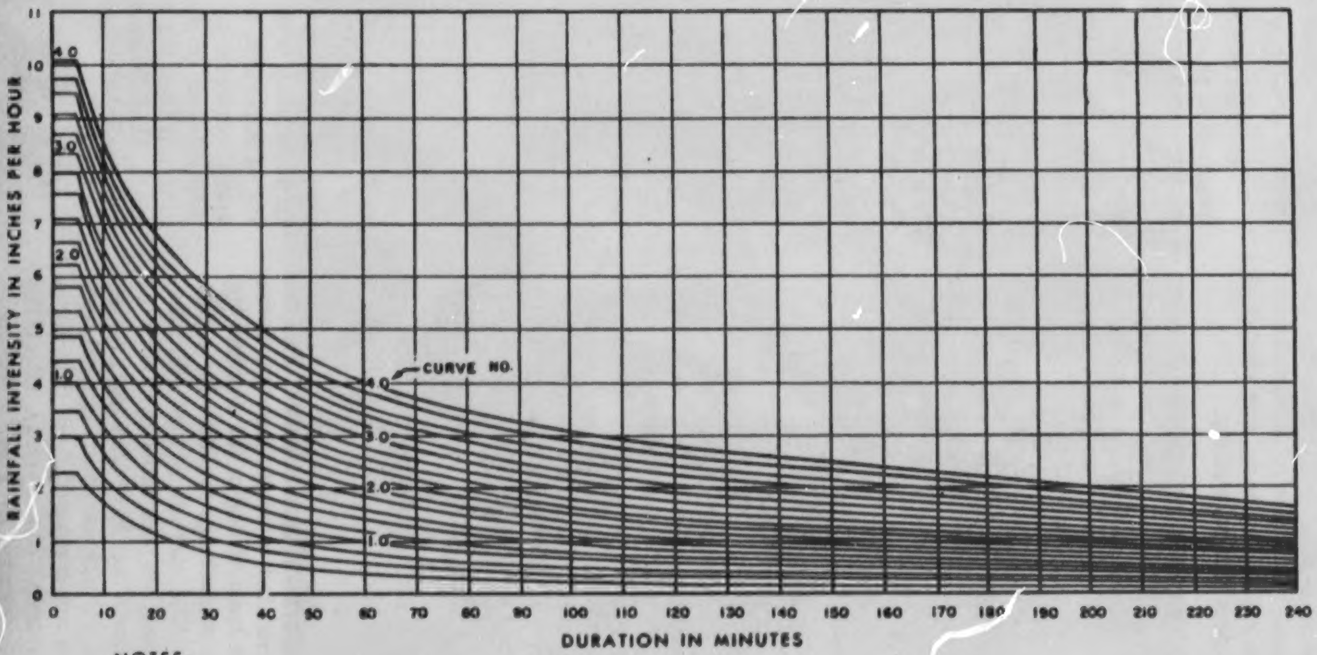
1-11. DRAINAGE RECONNAISSANCE

A ground reconnaissance should provide much additional information beyond that mentioned in the preceding paragraph. Such a reconnaissance is desirable because many conditions that affect drainage can be observed only by visiting the site. In many places, gullies and other drainage paths indicate the effects of previous rainfall. Puddles, soggy earth, and aquatic-plant growth all indicate that, for at least a portion of the year, the natural drainage is inadequate for construction work. Dry and cracked earth is a sign of loss of water through evaporation and may indicate an impervious subsoil and inadequate subsurface drainage. Adjacent streams should be studied, to determine the probability of floods and to determine the drainage outfall elevation. Similarly, in coastal areas, the elevation of high tide should be noted to determine the drainage outfall elevation and possible overflow. Springs, quicksand, seepage from steep banks, and other indicators of high ground-water levels should be looked for. The type, density, and extent of surface cover should be noted, since the presence or absence of vegetation greatly influences runoff characteristics of the area.

1-12. GENERAL PROCEDURE IN DRAINAGE DESIGN

Preliminary consideration of the type of installation required, the engineer resources available, and the amount and reliability of the data collected determines the degree of design necessary. The following steps are essential in the design procedure.

a. A very close study of a topographic map is made to identify the areas that may



NOTES:

1. Curve numbers correspond to one-hour values of rainfall or supply indicated by respective curves.
2. All points on the same curve are assumed to have the same average frequency of occurrence

Figure 1-5. Standard rainfall intensity-duration curves.

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contribute surface or subsurface flow to the construction site. The directions of all natural and subsurface flow, to and from the site, are determined. If a ground reconnaissance has not been made previously, one should be made to confirm this map study.

b. The proposed construction is then laid out on the largest-scale map or aerial photograph obtainable. Special attention is given to the utilization of natural drainage channels.

c. In the case of roads, a proposed grade and ground profile is then prepared. In the case of airfields, a working drainage drawing is made showing the layout and the tentative finished grading by means of contours. Drainage areas are outlined on the map, and their size obtained by scaling or planimetering.

d. The design discharge from each drainage area is determined, as described in lesson 2. Required sizes of channels, pipes, and culverts at critical points in the drainage system are then determined as outlined in the same lesson. Frequently, it will be necessary to make several drainage layouts before the most economical system, with a proper balance between grading, surface drainage, and subsurface drainage, can be selected.

1-13. DESIGN STORM

The design storm is that storm which may be expected to be equaled or exceeded on an average of one time during the design period.

a. The term "design-storm criteria" refers to the rainfall intensity-duration curve adopted as a basis of design for determining the capacity of drainage facilities for a particular area. The rainfall intensity-duration curves represent average rates of rainfall for various durations that have the same average frequency of occurrence. Such intensity-duration curves are computed from data for a number of storms; consequently, all of the intensities represented by a particular curve may not be expected in the same storm—at least not with the frequency indicated.

b. Drainage for military construction should be based on a 2-year design storm frequency, unless exceptional circumstances require greater protection.

c. The rainfall intensity-duration value required to produce the maximum drain-inlet discharge corresponding to a given design storm criterion, taking into consideration all drainage area characteristics and ponding effects, is referred to as the "design storm-rainfall". To simplify the preparation of generalized diagrams for estimating drain-inlet capacities required under various conditions for design storm runoff, rainfall is assumed to follow the standard rainfall-duration curve shown in figure 1-5.

d. The design-storm frequency serves as an index to the average frequency with which some portions or all of the storm-drain system will be taxed to capacity. The selection of the design storm frequency for a particular project must be based primarily upon judgment, with consideration of the purpose and importance of the given road or airfield and such economic and engineering limitations as may exist. The duration of rainfall required to produce the maximum rate of runoff will depend primarily upon the length of overland flow, taking into account surface detention, roughness factor, and other surface-runoff characteristics.

e. The design-storm frequency alone is not a reliable criterion of the adequacy of storm-drain facilities. In many instances, storms appreciably more severe than the design storm may cause very little damage or inconvenience, whereas, in other cases, flooding of important areas may result. It is generally advisable to investigate the probable consequences of storms more severe and less frequent then the design storm, before making a final decision regarding the adequacy of drain-inlet capacities.

1-14. CONSIDERATIONS FOR SUBSURFACE DRAINAGE

One of the first considerations of the engineering officer should be the selection of a construction site which eliminates or minimizes the need for surface and subsurface drainage. If it is impossible or impracticable to locate such a site, then one of the most important features of the design of a roadway or an airfield is the proper incorporation of a subsurface drainage system in the overall plan. The Highway Research Board has given the opinion that the majority of surface failures can be attributed to faulty subsurface drainage. Although the pavement protects the base to some extent from direct infiltration of water, it is possible for water to reach the base indirectly from less protected surface areas. It is the purpose of a well-designed drainage system to intercept this flow of water before it reaches a particular area, or to lower the water table, once the water has infiltrated into the soil.

1-15. RELATIONSHIP TO GRADING

The problems relating to subsurface drainage may best be handled when construction operations on a road or airfield are initiated because grading operations necessary for good drainage may be combined with grading operations necessary for the primary construction. The importance of the relationship of proper grading to good drainage cannot be overemphasized.

1-16. SOIL CHARACTERISTICS

The degree to which drainage becomes a problem depends to a large extent upon the characteristics of the soil where the construction is undertaken. Soils may be divided into three general groups as to their drainage characteristics:

a. **Well-draining.** Well-draining soils such as clean sands or gravels, may be drained by the use of a gravity system. In road and airfield construction open ditches may be used to intercept and carry away water that comes from the surrounding areas. In general, if the ground-water table around the site of a construction project is controlled in these soils, it will be controlled under the site, also.

b. **Poor-draining.** Poorly drained soils include organic and inorganic fine sands and silts and coarse-grained soils containing an excess of nonplastic fines. In general, the flow of water in such soils is impeded by their characteristic density. It may be quite difficult to lower the water table in such soils by the use of a gravity system alone. In certain cases, a system consisting of closely spaced perforated-pipe drains may prove effective. Another solution for a drainage condition of this type is to replace the relatively impervious soil with a pervious well-draining type. This is the best solution if the poor-draining soil is surrounded by a well-draining soil since this condition, if uncorrected, is very conducive to differential frost heave.

c. **Impervious soils.** Impervious soils are fine-grained, homogenous, plastic soils and coarse-grained soils containing plastic fines. Subsurface drainage is so slow in these soils that it is of little value in controlling their moisture content. Any drainage process in such soils may be difficult and expensive. The best means of securing adequate drainage would be to replace the impervious soil with a good pervious soil.

1-17. DESTRUCTIVE EFFECTS OF FROST ACTION

In certain climates where the air temperature may reach or go below the freezing point of water the combination of a high water table and poorly drained soils may result in frost heave or frost boil. These usually have a very injurious effect on any wearing surface, the extent of which depends upon whether uniform or differential heaving occurs.

1-18. UNIFORM HEAVE

Uniform frost heaving occurs if both the soil characteristics and the paving characteristics are the same over the area in question. It is necessary that conditions be similar throughout the area in order that the freezing process proceed uniformly. Although the ground level may displace upward, the displacement is the same over the entire area;

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hence no destructive cracks are caused by unequal displacement of adjoining sections.

1-19. DIFFERENTIAL HEAVE

Differential frost heaving, on the other hand, occurs when subsoil conditions are not uniform throughout the area, with the result that one section freezes and expands before, or to a greater extent than, an adjoining section does. Such differential movement can break up rigid pavements and cause serious harm to flexible pavements when coupled with the thawing process. Figures 1-6 and 1-7 show the effects of differential frost heave on rigid and flexible pavements.

1-20. KINDS OF THAWING

When the subgrade starts to thaw, the damage which results is dependent almost entirely upon the kind of thawing, since, depending upon weather conditions, thawing may proceed in three ways:

a. Thawing from the top down. This occurs when the air temperature suddenly rises from below the freezing point to well above it and remains there for some time. This type of thawing causes a difficult problem because the frozen layer below the thawing zone is impervious and represents a barrier through which the water coming from the top cannot pass. Since the soil beneath the pavement is in a supersaturated state it provides little support for the road surface and the repeated action of heavy wheel loads causes deflection of the pavement that displaces the soil particles and water directly beneath the pavement. This is what is known as "pumping", and is pictured in figure 1-8. If this continues, a void is formed under the pavement and failure ultimately occurs by cracking of the surface. The problem is particularly serious in soils of a silt or clay nature since they are inherently unstable if saturated. The best method of preventing this type of failure is to remove all silt and clay material in the base and subgrade during construction and replace it with a good pervious material, so that the water table is lowered well below the base course.

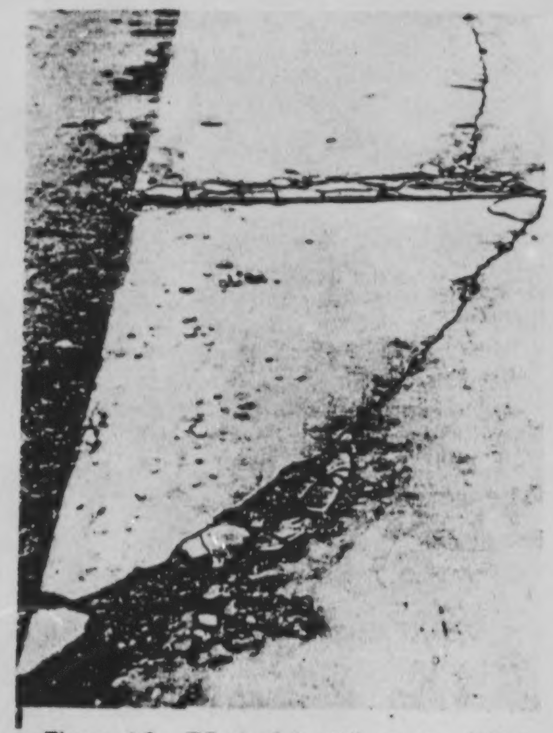


Figure 1-6. Effect of frost heave on rigid pavement.

Figure 1-7. Effect of frost heave on flexible pavement.

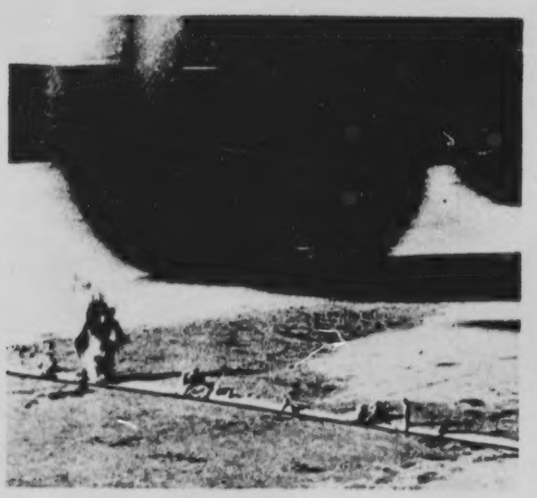


Figure 1-8. Pavement subjected to pumping.

b. Thawing from the bottom up. Thawing may also proceed from the bottom up in the event that the air temperature rises to just below the freezing point and remains there for some time. In this event, the material closest to the surface will remain frozen while the deeper material will thaw as a result of the transference of heat from the interior of the earth. In the case of an airfield or in highway maintenance, this is a very desirable condition since the water that is released has a ready and convenient route downward to the water table. If thawing proceeds in this manner, there is little tendency for a reduction of subgrade stability to occur.

c. Thawing from both top and bottom. When the air temperature remains barely above the freezing point for just long enough, a relatively trouble-free thawing process occurs both from the top down and from the bottom up. The melt water resulting from the thawing of the bottom portions of the frozen layer is disposed of as described in b above. The melt water resulting from the thawing of the top layers is not so excessive in quantity that surface runoff cannot handle it satisfactorily. Usually, much of the melt water from the top is dissipated satisfactorily by evaporation into the air. In certain soils and under certain conditions, however, thawing of this nature can produce a most difficult condition, referred to as a frost boil. When the air temperature remains barely above freezing for a prolonged period of time, thawing from the bottom upward proceeds much more rapidly than from the top downward. While in most soils this would not be undesirable, it can become so in plastic soils such as clays. The excess water developed by the melting of the ice layers cannot be dissipated by this soil rapidly enough, and a semiliquid unstable mud layer develops. As long as this mud is trapped beneath a substantial frozen layer, no difficulty exists. But as the frozen layer decreases in thickness it becomes too thin to bear traffic stresses and breaks in spots. The very unstable mud then oozes through the breaks. This supersaturated, semiliquid soil is incapable of withstanding any appreciable load.

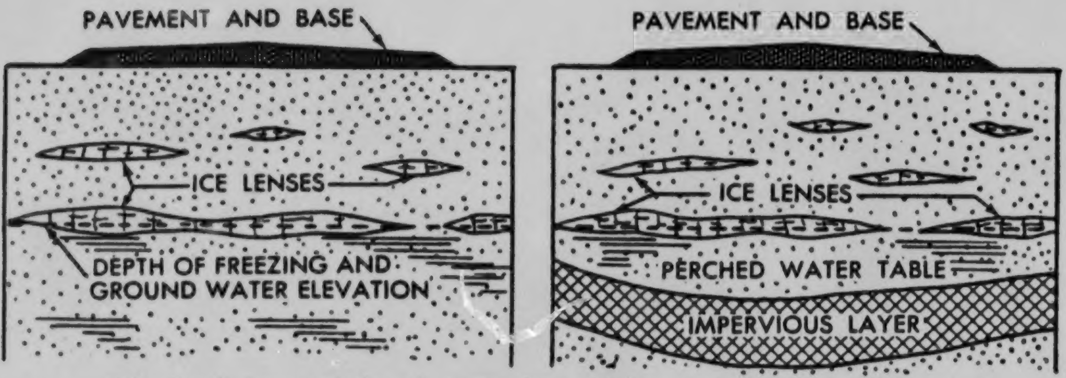
1-21. SOURCES OF FROST-ACTION WATER

There are three principal sources of water (illustrated in fig 1-9) that will provide an adequate supply for the frost-action process:

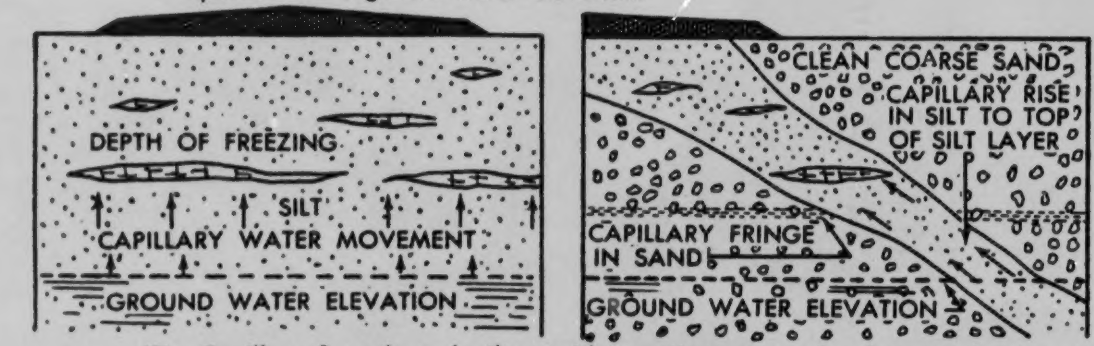
a. A high water table which is 5 feet or less below the finished grade line.

b. A capillary supply from an adjoining water table. This is particularly a problem in silty soils which have a high capillary rate. Clays have a rather low capillary rate so that frost heaving is not as severe as in silts although thawing problems are greater than in silts.

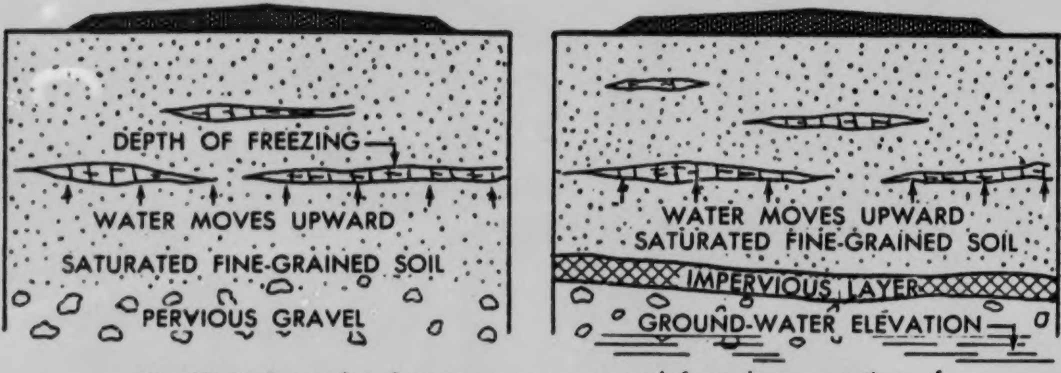
c. A saturated condition of fine-grained soils at or below the freezing stratum. Frost action is usually most severe in soils with a high moisture content.


PAVEMENT AND BASE
ICE LENSES
DEPTH OF FREEZING AND GROUND WATER ELEVATION
PAVEMENT AND BASE
ICE LENSES
PERCHED WATER TABLE
IMPERVIOUS LAYER

(1) Continuous supply of water from high ground-water table. Growth of ice lenses extremely rapid when depth of freezing penetrates to ground-water elevation.


DEPTH OF FREEZING
SILT
CAPILLARY WATER MOVEMENT
GROUND WATER ELEVATION
CLEAN COARSE SAND
CAPILLARY RISE IN SILT TO TOP OF SILT LAYER
CAPILLARY FRINGE IN SAND
GROUND WATER ELEVATION

(2) Capillary flow through silt provides continuous supply of water despite depth of ground-water table below depth of freezing. Inclined silt layer may dip into ground-water a considerable distance away from structure.


DEPTH OF FREEZING
WATER MOVES UPWARD
SATURATED FINE-GRAINED SOIL
PERVIOUS GRAVEL
WATER MOVES UPWARD
SATURATED FINE-GRAINED SOIL
IMPERVIOUS LAYER
GROUND-WATER ELEVATION

(3) Limited supply of water moves upward from lower portion of saturated fine-grained soil.

Figure 1-9. Sources of water for the frost-action process.

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REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space below the question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in back of this booklet. Do not send in your solutions to these review exercises.

1. When commencing work on a construction project, what should be accomplished by the first work that is done? (1-1)

2. What factor determines whether drainage is to be classified as surface drainage or subsurface drainage? (1-2)

3. What is the simplest, cheapest, and most efficient method for handling surface water? (1-3c)

4. What is the principal difference in the layout of a storm-drainage system and a sanitary system layout? (1-3d)

5. What are the four types of structures most commonly used in military construction for the control of ground water? (1-4)

6. When work on a road or airfield construction project must be temporarily suspended, what action should be taken with regard to drainage? (1-5c)

7. How much crown is required in a gravel road to insure runoff of surface water before it can penetrate and wet the subgrade? (1-7a)

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8. What is the most important factor which will contribute to the success of an airfield drainage system? (1-8b)

9. Under what conditions would hasty design procedures probably be used in the design of a road or airfield? (1-9b)

10. What basic information is considered to be of primary importance in designing a drainage system that will insure prompt removal of surface water and positive control of ground water? (1-10b)

11. What are three variable conditions of a particular soil which would influence that soil's capacity to absorb precipitation? (1-10c)

12. If, on a ground reconnaissance you observe an area of dry and cracked earth, what would this condition indicate to you? (1-11)

13. What are the necessary considerations in determining the degree of design necessary for a specific drainage system? (1-12)

14. What is the definition of a design storm upon which the design for a drainage system is based? (1-13)

15. Under normal conditions, what is the design storm frequency used for military construction? (1-13b)

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16. What are the principal factors that determine the duration of rainfall required to produce the maximum rate of runoff? (1-13d)

17. During the process of constructing a road or airfield, what is the best time to take care of subsurface drainage problems? (1-15)

18. What is the characteristic of soils which are made up of organic and inorganic fine sands, silts, and coarse-grained soils containing an excess of nonplastic fines, which is of concern in drainage? (1-16b)

19. What is the most likely effect that thawing of a subgrade from the top down may have upon a paved surface above that subgrade? (1-20a)

20. When the air temperature just above a frozen subgrade raises to just below the freezing point and remains there for some time, what happens to subgrade stability? (1-20b)

LESSON 2

SURFACE RUNOFF (Hasty and Rational Methods)

CREDIT HOURS ------------------------ 4

TEXT ASSIGNMENT ------------------- Attached memorandum.

MATERIALS REQUIRED ---------------- Annex A.

LESSON OBJECTIVE ------------------- To teach you how to calculate surface runoff.

SUGGESTIONS ------------------------ Read the attached memorandum through rapidly to obtain a knowledge of its scope. Then read it through carefully, underlining the important points and objectives. Read the review questions at the end of the lesson. Study the lesson, searching for answers to the review questions, and write your answers in the spaces provided. Finally, check your answers with the answers given for this lesson at the back of this booklet. Review as necessary.

ATTACHED MEMORANDUM

Section I. INTRODUCTION

2-1. GENERAL

There are several methods that may be used to determine the amount of runoff from a given area, and the size of drainage structure(s) required. Methods range from hasty to deliberate. The method used will depend upon time available, importance of the structure being protected, and the length of time it will be used. This lesson will cover the Hasty Method which is a rapid, field method for estimating the size of a drainage opening required, and the Rational Method which is a deliberate method used for calculating the quantity of runoff from a given area to culvert or other point of interest. The subject of drainage is highly complicated, and is sometimes controversial. Drainage problems in the field should receive benefit of the most experienced and the best engineering judgment available.

2-2. FACTORS INFLUENCING RUNOFF

Before going into the methods for calculating requirements for drainage structures, it may be well to consider some of the factors involved, other than rainfall.

a. There are many factors which affect the rate and quantity of surface runoff. The size, shape, and slope of the drainage area are the most important.

b. The first step in determining the size of a drainage area is an analysis of the flow pattern of the water in the general vicinity.

From this analysis the actual area contributing runoff to the drainage outlet is apparent and the outline of the drainage area can be drawn.

c. The process of marking this drainage area boundary or divide on a map is known as **delineation.** Usually a divide will follow ridges and high points on saddles. The outlining of a drainage area is best accomplished on a topographical map which has a scale of 1 inch equals 200 feet (1:2400) or larger, and which shows the final proposed layout and contours.

d. The **size** of an area affects runoff in two ways. First, a large area will have a longer period of time over which runoff will occur, and the peak runoff rate will be less per acre than for a smaller area, assuming that the total runoff per acre remains the same. Secondly, the maximum intensity of rainfall for a given frequency varies inversely with the area covered by the storm, thus lowering the peak runoff.

e. The **shape** of a drainage area governs the rate of runoff because it controls the length of overland flow.

f. The average **slope** (S) of a drainage area controls the time (T) of overland flow. As the average slope of an area increases, the time of overland flow decreases, and the rate of runoff increases.

g. Areas are classified as either **simple areas** or **complex areas.** A simple area has 80 percent or more of its total area covered by **one** type surface (turf, concrete, etc.). A complex area has two or more types of surface, but no one type of surface amounts to as much as 80 percent of the total area.

h. The drainage area may be subdivided by lines which separate overland flow representative of one portion of the area from the overland flow representative of other portions of the area. Areas thus delineated are known as **subareas.**

i. When the outflow of an area, either simple or complex, contributes to the outflow of another area, either simple or complex, the total outflow is considered as runoff from **successive areas.**

j. Distances are scaled from a map, grading plan, or drainage-layout drawing. Slopes are estimated by methods taught in basic map reading. Exercises in this subcourse will be based upon the average slope for the path of flow being investigated. If a point is located between two contours, estimate its elevation by interpolation. Determine the difference in elevation between the two points, scale the distance of flow (DOF), and calculate the average slope. In determining the slope of a ditch where culvert invert elevations are given, assume that a uniform ditch slope exists between the culverts. The invert elevation is the elevation of the lowest point of the inside perimeter at the end of the culvert.

k. A path of flow is the route that surface runoff will follow to the area outlet. Runoff will flow from higher elevation to lower elevation in a direction perpendicular to the contours. Generally there are so many possible paths of flow that it would be impractical to consider all of them; therefore, paths of flow are selected on the basis of being most representative in length and slope of all the paths of flow occurring in the area or subarea. The number of representative paths of flow from the subareas should be selected in proportion to the size of the subarea with respect to the total area.

l. There are three general types of flow to be considered: sheet flow, channelized flow, and ditch flow. Sheet flow is water that flows at a more or less equal depth in a blanket across a uniform or nearly uniform surface such as a grassed field, surfaced road, runway, parking area, or roof. As a general rule water begins to channelize or collect into ditch-like flow when it flows across surfaces not protected by paving or structures designed specifically for erosion prevention such as plowed contours and terraces. Except in the cases where channelization is specifically prevented, sheet flow should be expected to become channelized flow after a distance of not over 400 feet in very flat, smooth terrain and much sooner in rough, steep terrain. If reconnaissance can not be made, 200 feet may be used as an average length of sheet flow.

m. The length, designated by the symbol "L", of sheet flow is the horizontal distance measured along the representative path of sheet flow from the area divide to the beginning of channelized flow or ditch flow. Channelized flow and ditch flow lengths are horizontal distances measured along their respective paths of flow.

n. Retardance, designated by the symbol "n", is the term used to designate the resistance to sheet, channelized, and ditch flow caused by various surface conditions such as vegetation, surface, and alignment in the path of flow. The factors that determine the "n" for the different types of flow are dissimilar, but available data indicates that the retardance values in table 2-1 are approximately representative of most surfaces encountered.

TABLE 2-1. *Retardance Coefficients*

Type of Surface	"n"
Smooth Pavement	0.02
Ditches	0.02
Compacted Gravel Surfaces	0.06
Bare Surfaces	0.1
Channelized Flow from Average Grass Cover	0.2
Sparse Grass Cover	0.2
Average Grass Cover	0.4
Dense Grass Cover	0.8

Section II. THE HASTY METHOD

2-3. HASTY METHOD OF DETERMINING RUNOFF

Compute the cross-sectional area of the ditch or gully in which the culvert or drainage structure is to be built, using the high-water mark to determine the height and the position of the upper width. To find the cross-sectional area required for the drainage structure, double the cross-sectional area of the channel (fig 2-1).

$$\text{Channel area} = \frac{(b_1 + b_2)}{2} h$$

Structure area = 2 times channel area or

$(b_1 + b_2)\ h$; where

b_1 = bottom width in feet

b_2 = upper width in feet

h = vertical distance between upper and lower width in feet

2-4. EXAMPLE

What is the required structure area for a stream that has the following characteristics: width of stream bottom, 4 feet; depth at high-water mark, 3 feet; width at high-water mark, 6 feet.

$$\text{Channel area} = \frac{(4 + 6)}{2} \times 3 = 15 \text{ sq ft}$$

$$\text{Structure area} = 2 \times 15 = 30 \text{ sq ft}$$

a. From the above problem it can be seen that a culvert installed at this point in the stream must have a minimum cross-sectional area of 30 sq ft.

b. This method does not directly take into account the size, shape, and slope of the area, surface vegetation, condition of the soil, or rainfall intensity, but, instead, goes to the outlet conditions for the estimating factor. This hasty calculation is used only when time does not permit a more exact method.

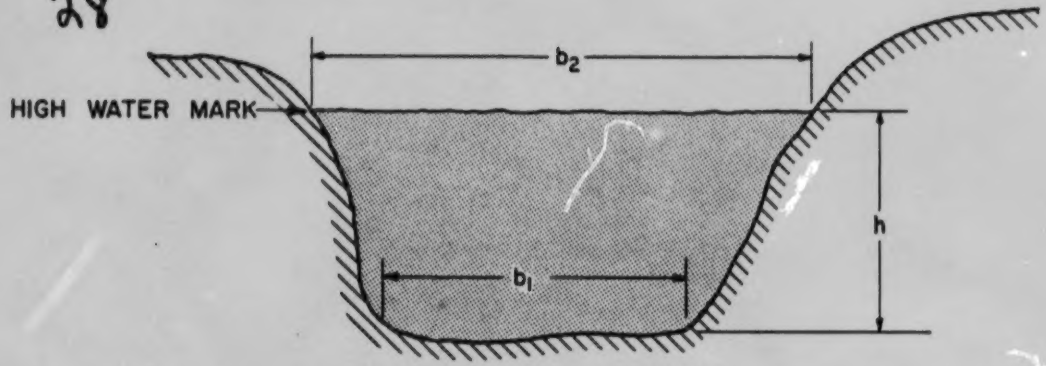


Figure 2-1. Ditch section.

Section III. THE RATIONAL METHOD

2-5. PURPOSE

The rational method is used to determine the runoff that can be expected from a given area. To use it effectively requires a study of many variables such as the terrain, slopes, soil, vegetation and the hydrology of the area. It will be the purpose of this section to discuss in detail, the rational method and its variable parts, and the use of the method in determining the runoff from different types of drainage areas.

2-6. RATIONAL METHOD

a. The rational method utilizes the empirical equation:

$$Q = CIA$$

where:

Q = Runoff from a given drainage area in cubic feet per second (cfs)

C = Coefficient representing the ratio of runoff to rainfall.

I = Intensity of rainfall in inches per hour of the storm generating maximum runoff.

A = Drainage area in acres.

b. **Assumptions for use.** Before discussion of the equation and its variable parts, the following basic assumptions must be stated:

(1) Entire drainage area is contributing to the runoff.

(2) Rainfall intensity is maximum and equal over the drainage area.

(3) The area has a regular shape.

(4) The use of the method is limited to areas not exceeding 3,000 acres.

(5) The area has homogeneous soil type and vegetative cover. In the event this is not so, further assumptions are made as follows:

(a) Simple area — One type of soil and cover predominates in 80% or more of the area.

(b) Complex area — One that is composed of two or more different soil types, cover, or man-made areas, no one of which constitutes 80% or more of the area.

2-7. RUNOFF COEFFICIENT C

It is known that when it rains some of the rainfall is "lost" due to infiltration, evaporation and interception. As a result of these losses all of the rain falling on a given area does not run off. The "C" value used in the rational method expresses as a ratio the percentage of rainfall that is expected to run off Expressed mathematically the value of "C" is the ratio of runoff to rainfall or $\frac{\text{Runoff}}{\text{Rainfall}}$.

a. **Basic "C" value.**

(1) The basic value of "C" is taken from table 2-2. For example, review of the table shows that asphalt has a "C" value of .80 - .95. What is implied is that 80 - 95% of the rain that falls on an asphalt surface will run off. From the type of material this is what would be expected. Consider the rainfall runoff from a beach sand. It is very small, if any, due to the beach sand being a pervious material. From table 2-2, it is found that the "C" value for a pervious soil is 0.01 to 0.10. This means that only 1 to 10% of the rainfall on a pervious soil will run off and that 90 to 99% will be lost. The loss is primarily due to infiltration.

(2) In table 2-2 there are only three general types of soil listed, "pervious", "slightly pervious", and "impervious", each given a "C" value range with and without cover. In order to correlate these basic soil types with soils defined and classified under the Unified Soil Classification System (USCS) table 2-3, which is an extract of a USCS soil characteristics table, has been included here. The three general soil types as shown in table 2-2 correspond, in drainage characteristics, to soils in table 2-3 as follows:

Pervious ____________Excellent

Slightly pervious ____Fair to poor

Impervious _________Poor to practically impervious

A GW soil has excellent drainage characteristics, which means it is very porous. A GM_u soil has poor to practically impervious characteristics, which means it is impervious.

(3) The values in table 2-2 for the differing soil descriptions are specified with and without turf (vegetation). Note the difference between the C values for a soil type with and without turf. The "with turf" C values are lower, indicating more loss and less runoff. This is caused by the turf retarding the flow and thereby allowing more time for the water to infiltrate into the soil.

(4) With reference to table 2-2 it will be noted that for each type of material the C value has upper and lower limits. Judgment, achieved by field experience, will determine the C value to use in the calculations. Until this experience is achieved it is recommended that the higher limit be used.

b. **Corrected "C" value.**

(1) In the use of table 2-2 it will be noted that asterisks (*) are placed after each surface type except woods and the man-made surfaces. The footnote to table 2-2 requires that for these surfaces the "C" value be adjusted for slopes greater than 2%. Expressed mathematically the correction is

$$(S_{\text{average}} - 2)\ 0.01 + C_{\text{assumed}} = C_{\text{corrected}}$$

Where:

S_{average} = Average slope of the area

C_{assumed} = Table value at "C"

$C_{\text{corrected}}$ = "C" corrected for slope

The reason for the correction is that as the ground slope increases the rainfall runoff will flow at a faster rate over the ground surface. The effect of this speedup is to reduce the time available for the water to infiltrate into the soil. The reduction of this loss, due to infiltration, will increase the amount of runoff, thereby increasing the ratio of runoff to rainfall. This in effect will cause an increase in the value of "C".

(2) The surface slopes within the area will, as previously described, have an effect upon the value of C. Since the losses that occur take place over the entire area, it will be necessary to determine an average slope representing the entire area. In order that the average slope will be representative of the area, care should be taken to make certain that the slopes selected will represent approximately equal areas. Since the loss effect is a function of surfaces, the slopes of channels or ditches are not to be considered.

TABLE 2-2. *Surface Runoff Coefficients*

TYPES OF SURFACE	FACTOR (C)
Asphalt pavements	0.80 to 0.95
Concrete pavements	0.70 to 0.90
Gravel or macadam pavements	0.35 to 0.70
Impervious soils*	0.40 to 0.65
Impervious soils with turf*	0.30 to 0.55
Slightly pervious soils*	0.15 to 0.40
Slightly pervious soils with turf*	0.10 to 0.30
Pervious soils*	0.01 to 0.10
Wooded areas (depending on surface slope and soil cover)	0.01 to 0.20

*For slopes from 1 to 2 percent.

NOTE: The figures given are for comparatively level ground. For slopes greater than 2%, the factor should be increased by 0.01 for every 1 percent of slope, up to a maximum C of 1.0.

Use of "C" Value Table

1. Determine drainage characteristics of soil type(s).
2. Correlate terminology with terms used in "C" value table (Terms correlated in paragraph 2-7a(2)).
3. Locate the soil and/or cover type in the left column of table 2-2. Read the highest value of the range listed in the column at the right for that type of soil and/or cover.
4. This is the "C" assumed value. For slopes greater than 2%, those values marked with an asterisk (*) must be corrected using the following formula:

$$(S_{average} - 2)\ 0.01 + C_{assumed} = C_{corrected}$$

TABLE 2-3. *USCS Soil Characteristics (Extract)*

MAJOR DIVISIONS		LETTER	DRAINAGE CHARACTERISTICS
(1)	(2)	(3)	(11)
Coarse Grained Soils	Gravel and Gravelly Soils	GW	Excellent
		GP	Excellent
		GM d	Fair to Poor
		GM u	Poor to Practically Impervious
		GC	Poor to Practically Impervious
	Sand and Sandy Soils	SW	Excellent
		SP	Excellent
		SM d	Fair to Poor
		SM u	Poor to Practically Impervious
		SC	Poor to Practically Impervious
Fine Grained Soils	Silts and Clays LL $<$ 50	ML	Fair to Poor
		CL	Practically Impervious
		OL	Poor
	Silts and Clays LL $>$ 50	MH	Fair to Poor
		CH	Practically Impervious
		OH	Practically Impervious
Highly Organic Soils		Pt	Fair to Poor

c. Weighted "C" value.

(1) One of the assumptions made in the rational method is that there is homogeneous soil type and cover throughout the area. In many cases, the area will comprise combinations of soil types and cover and even include man-made structures. In these cases it would be impossible to determine a single value of C to use in the rational equation. It will be necessary in such cases to use some technique to determine a C value to represent the area. To do this it must be determined if the area is simple or complex. If one type of cover and soil predominates in 80% or more of the area it is a "simple" area and the "C" value for that particular soil and/or cover type controls. In the event no one type of cover or soil predominates in 80% of the area, it is a complex area and the "C" value must be weighted. In this case a mathematical proportion of the subareas and their respective "C" values must be made.

(2) It should be noted that before the "C" value is weighted the "C" value assumed for each subarea must be corrected for slope. The correction for slope will be made if the average slope of the subarea is greater than 2%.

(3) The weighting of the "C" value is accomplished by multiplying the corrected "C" value by the subarea that is affected by that "C" value, summing the products and dividing by the total area. Expressed mathematically the formula is:

$$C_{\text{weighted}} = \frac{C_1A_1 + C_2A_2 + C_3A_3 —}{A_1 + A_2 + A_3 —}$$

Furthermore if the area is considered complex, each subarea and its respective "C" value must be included in the weighting process. This is done no matter what percentage of the total area the subarea represents.

2-8. INTENSITY

a. Prior to the study of this paragraph it will be necessary to review the assumptions made in paragraph 2-6(b) of this lesson. Also, paragraph 1-10, lesson 1, should be reviewed for the intensity duration relationships of rainstorms.

(1) Using the above referenced assumptions and intensity duration relationships developed, it will be found that for a given area only one particular storm will give a maximum discharge (Q). This particular storm is the one that rains over the entire area being drained for a period of time just long enough for the runoff from all segments of the area to reach the outlet at the same time. This time is called the area time of concentration, or TOC. A storm of shorter duration than this area TOC would not last long enough for the runoff from the more distant segments of the area to reach the outlet together with runoff from segments near the outlet. Therefore, the runoff would not be maximum.

(2) With reference to Figure 2-2 it will be noted that all the area below the 10-minute line will drain in 10 minutes or less. Runoff from the area between the 10 and 20-minute line will reach the outlet in not less than 10 minutes but will have drained in not more than 20 minutes. Similarly the runoff from the area between the 20 and 30-minute line will reach the outlet in not less than 20 nor more than 30 minutes. At the end of 30 minutes the entire area is draining; therefore the time of concentration (TOC) for this area is 30 minutes.

(3) Again referring to Figure 2-2, if a storm of 20-minutes duration sweeps over the area then two possibilities exist:

(a) The entire area was not wetted and therefore only a portion of the area will drain.

(b) The entire area was wet, but, since the storm duration was only 20 minutes, all the area below the 20-minute line had drained through the outlet before the runoff from the area between the 20 and 30-minute line had reached the outlet. The entire area,

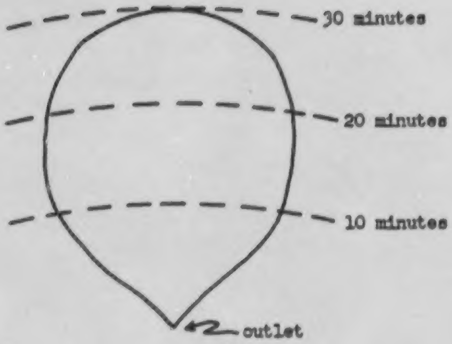


Figure 2-2. Illustrative "regular" drainage area.

therefore, is not contributing runoff to the outlet at one time.

(4) For a storm duration of 30 minutes, then, the entire area is contributing runoff to the outlet at one time, for the runoff from the closer areas has been replaced by more rain. The area has now reached critical flow, or peak Q.

(5) A storm whose duration is longer than the area TOC will have a lesser intensity. Reference to the intensity duration curves in lesson 1 will show that as the duration of the storms increase, the intensity decreases. From examination of the equation Q = CIA, it is obvious that as "I" decreases the Q will decrease. The critical storm then, is the storm whose duration is equal to the TOC.

b. Time of concentration (TOC).

(1) Representative flow.

(a) Based upon the discussion in b above, the area TOC must be determined. This is done by determining representative flow paths. A flow path can be defined as the path a raindrop will follow from the time it reaches the ground until it reaches the outlet. The flow path is called representative because it must approximate runoff traveling from the majority of the area until it reaches the outlet point. It is representative of the time at which the majority of the area will be contributing runoff to the outlet point. Establishing representative flow paths is based largely on experience, judgment, and trial.

(b) The assumption previously made was that the areas were "regular" in shape. The area depicted in figure 2-2 with no projections or protrusions is such a "regular" area. In nature, however, most areas are irregular in shape, as illustrated in figure 2-3. In such irregular shaped areas it is especially critical that the flow paths chosen are indeed representative of the time required for the majority of the area to drain. This is demonstrated by the following example.

(c) With reference to figure 2-3, all the area below the 10-minute line will drain in 10 minutes; the area below the 20-minute line will drain in not more than 20 minutes and so on up to the 40-minute line. Flow lines a, b, and c have been determined. Assuming that 90% of the total area lies below the 30-minute line, it then will have drained in 30 minutes or less. Runoff from the remaining 10% will reach the outlet in not less than 30 nor more than 40 minutes. Flow paths a and c should be chosen as the representative flow paths and used to determine the TOC. The reason is that they are indicative of the time it will take the runoff from a majority of the area to reach the outlet. Line b is not representative.

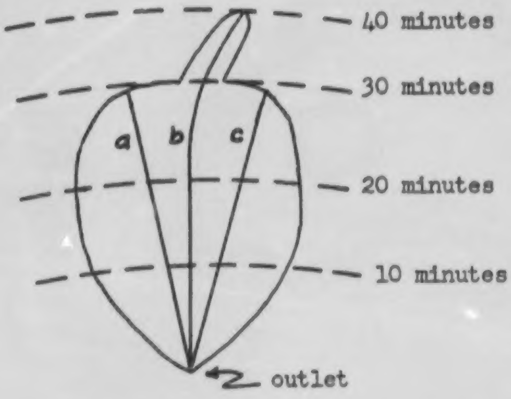


Figure 2-3. Illustrative "irregular" drainage area.

(d) To illustrate the importance of selecting representative flow lines, take the following example. Let "C" arbitrarily equal 1.0., and assume that the 1 hour, 2 year intensity is 2.0 inches per hour. If a storm of 40 minutes duration occurs, the entire area (100 acres) will be wet, and at 40 minutes, contributing water to the outlet point. The intensity (I) for a 40 minute storm is 2.7 inches/hour (curve No. 2, fig 1-5). The estimated runoff then is:

$$Q = CIA = (1.0)\ (2.7)\ (100) = 270 \text{ cfs.}$$

Taking this storm for a 30 minute duration, the intensity would be 3.2 inches per hour. At the end of 30 minutes, 90 percent (90 acres) will be contributing water to the outlet. The estimated runoff then is:

$$Q = CIA = (1.0)\ (3.2)\ (90) = 288 \text{ cfs,}$$

which is a larger discharge rate than estimated using the entire area.

(e) Flow paths must be chosen that are representative of the time required for a majority of the area to drain. As has been shown, a shorter storm of higher intensity may cause a larger flow from the area. After all the flow paths have been chosen and timed, the times should correspond to each other within a few minutes. If the times are not relatively close, a careful check must be made to determine why, and an assessment made of the area to determine which of the times will produce the critical flow.

(2) Time of flow.

(a) After the representative flow paths have been established, the amount of time it will take the runoff to reach the outlet, as it travels along the established path, must be determined. In order to do this the type of flow must be either determined by observation or assumption. The flow types existing along a flow path are differentiated based on velocity and are of two types as follows:

1. Overland or sheet flow, which has a low velocity. In nature, normally, this type of flow does not exist for distances more than 400 feet. When observed, this type of flow has a smooth, uniform, almost glossy appearance. Direct observation is the preferred method of establishing this type of flow. When direct observation cannot be made, then some distance must be assumed. Since this is a matter of judgment nearly any distance can be assumed providing it does not exceed 400 feet. One method of reducing possible error is to arbitrarily establish 200 feet as the length of sheet flow when direct observation cannot be made. If 200 feet is used, and the actual sheet type of flow is between 50 and 400 feet, the error in time calculations for most slopes is only in the order of 3-4 minutes. If, however, either 50 or 400 feet is selected and the actual distance is at the opposite end of the range, then the time error for most slopes can be approximately 8 minutes. This can induce an error in the selection of the intensity of rainfall.

2. Ditch type flow which has a high velocity and is turbulent. This type of flow takes place in ditches and channels but is not limited to such channels and ditches. Ditch type of flow can exist over the entire flow path except for the distance that is determined to be sheet flow. When observed, ditch type of flow appears rough and channelized.

(b) Several factors are going to affect how fast the water runs and, consequently, how long it will take the water, or runoff, to reach the outlet. The two major factors are the slope and the cover. Slope affects the velocity of flow, for the steeper the slope the faster the flow. The cover provides resistance to the flow, thereby retarding the flow, thus reducing the velocity. In either case, changing the velocity of flow will have a direct bearing on the time of flow.

(c) Figure 2-4 is used to determine the time required for the runoff to travel along the flow path.

1. After choosing the flow paths that are thought to be representative of the area, each of these are then broken down into their sheet and ditch type of flow. The slope and cover are determined for the sheet flow and the slope and type for the ditch or channel flow. The ditch or channel flow along the same path could occur first as ditch flow in natural surfaces and then pass into a lined (asphalt or concrete) channel. In this case each would be timed separately, natural surfaces would be ditch flow and in a lined channel, paved surface flow.

2. Example. A flow path has 200 feet of overland flow over poor turf with a slope of 5%. It then has 700 feet of ditch type of flow over the same surface with a slope of 2% and finally passes into a concrete-lined channel with a length of 800 feet and slope of 1.5%. Go into figure 2-4 with the index of poor or sparse turf and horizontally to the 5% curve. Follow this curve to 200 feet, then vertically down to read 8 minutes. The ditch time over natural surfaces is obtained by going to the ditch index and with similar procedure read 10 minutes. For lined channels the index to use is paved surfaces. Using the procedures previously described, the 800 feet at 1.5% gives a time of 9 minutes. Compiling the results gives:

Overland Flow Time	=	8 min
Ditch Type Flow	=	10 min
Lined Channel Flow	=	9 min
Total Time	=	27 min

The time of concentration for the path would be 27 minutes.

c. Intensity of a particular storm (I). When the area TOC has been established and set equal to the critical storm duration, the intensity of that storm can be determined. This particular intensity "I" is the intensity to be used in the equation Q = CIA. What is now required is the curve number to be used in determining the intensity of a particular storm. The curve number is equivalent to the intensity in ins/hr of the one-hour, two-year frequency storm for the particular location of the facility.

(1) To obtain the intensity in ins/hr of the required one-hour, 2-year frequency storm refer to the world isohyetal map, figure 2-5. If the location falls directly on an isohyetal line, then the value of that line is the required intensity. In the event the location falls between two isohyetal lines, select the line with the highest value. **Do not interpolate.** The following examples are a list of areas or places and the one-hour, 2-year rainfall intensities as determined from the isohyetal map:

Southern Australia	1.0 in/hr
Florida	2.5 ins/hr
Washington, D.C.	1.5 ins/hr
Cuba	2.5 ins/hr
New Orleans, La.	2.5 ins/hr

(2) To obtain the intensity of a particular storm duration, referred to as TOC, use is made of the intensity-duration curves (figure 1-5, lesson 1). The curve number to be used is the intensity as found in paragraph (1) above. The storm duration is equal to the TOC of the area. For example:

(a) The project is to be located in Southern Australia, intensity 1.0 ins/hr, and the TOC is 25 minutes. Refer to figure 1-5, lesson 1; select curve number 1.0, follow the curve to 25 minutes and then horizontally to read an intensity of 1.8 inches per hour for the TOC.

(b) The project is located in Florida, intensity 2.5 in/hr, and the TOC is 50 minutes. Referring to figure 1-5 again, it will be required to interpolate between curves. Follow the curve and at 50-minutes storm duration move horizontally and read an intensity of 2.8 ins/hr for the TOC.

2-9. AREA

a. The last variable that must be determined to solve the equation Q = CIA is "A", the area in acres. This is the area of discharge, but before the size can be determined it must be defined. This is done by delineating or determining the boundaries of the watershed. The largest scale topographic map available of the area involved should be used for delineation. The map should be studied closely, and a ground reconnaissance

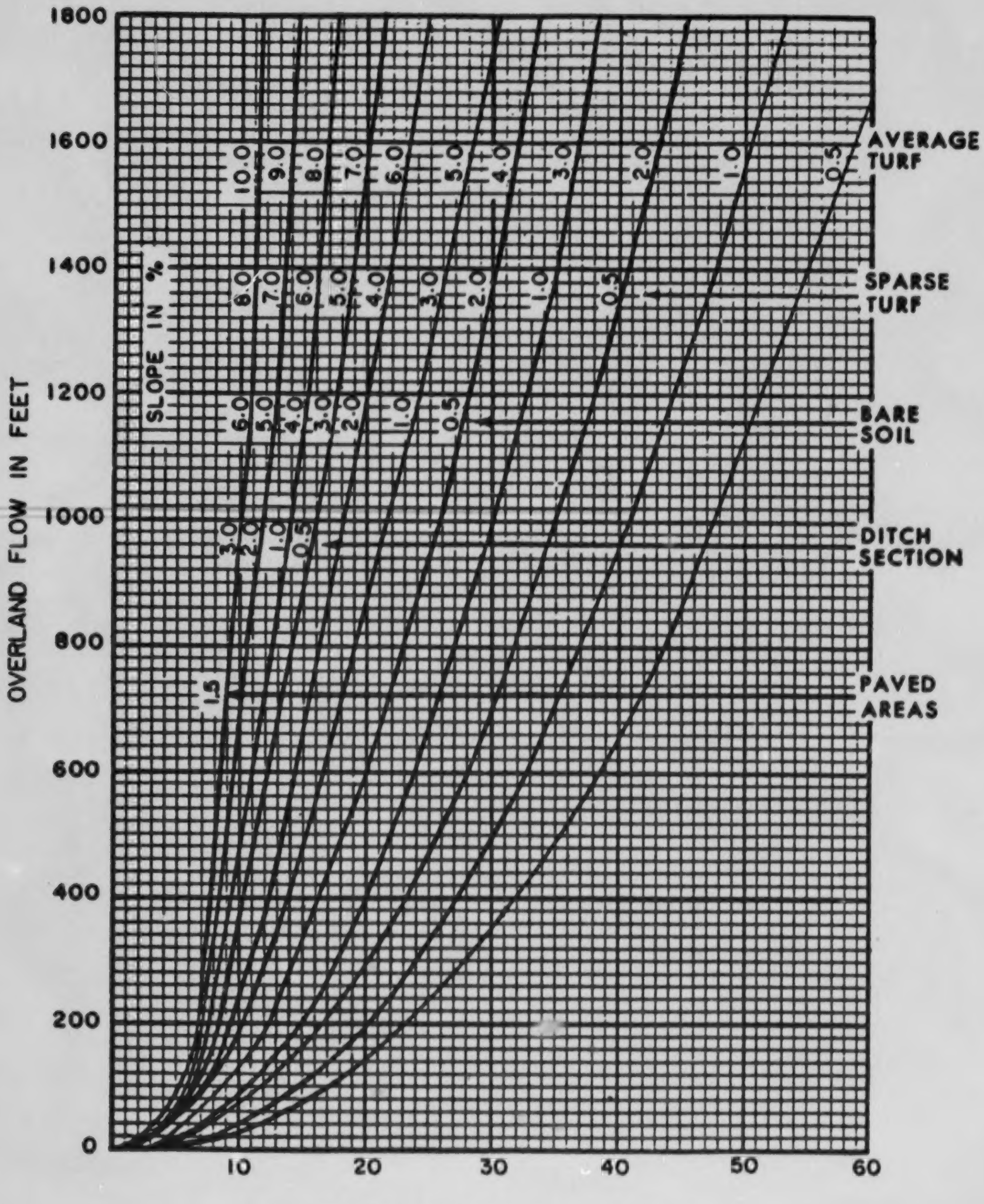
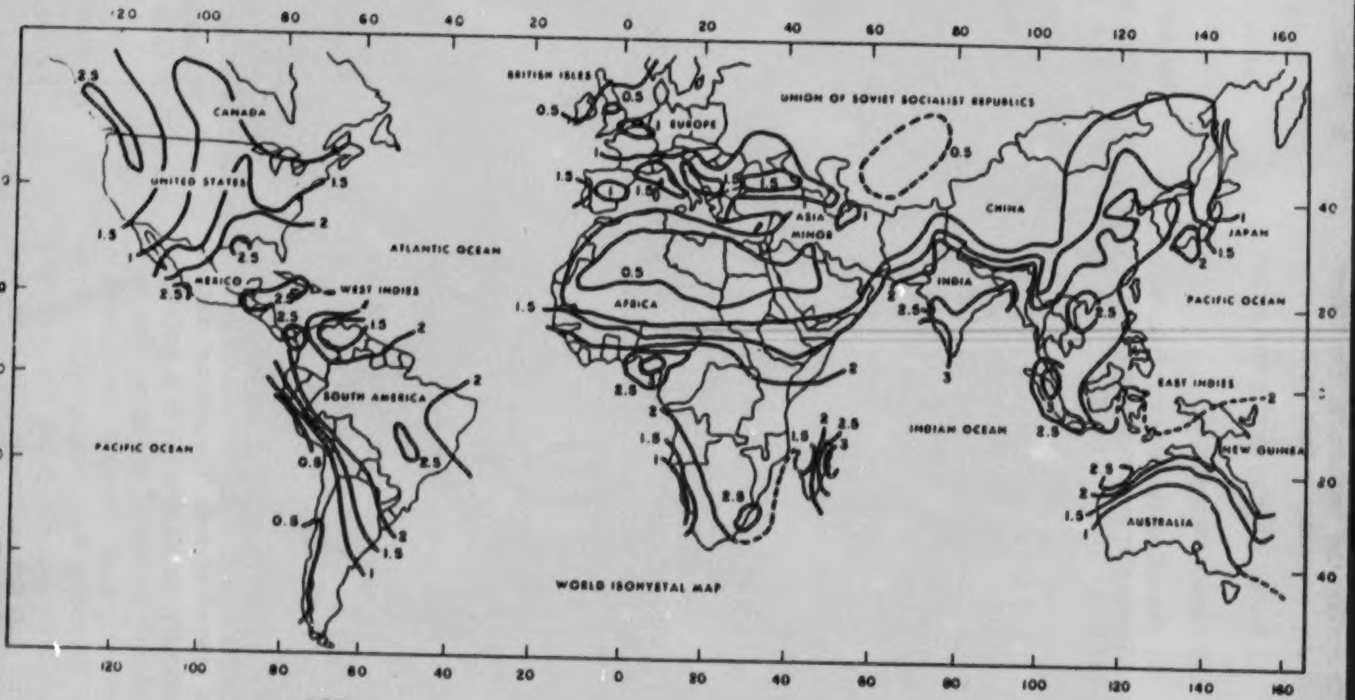


Figure 2-4. Curves for time of overland flow.


WORLD ISOHYETAL MAP
CANADA
UNITED STATES
MEXICO
WEST INDIES
SOUTH AMERICA
ATLANTIC OCEAN
PACIFIC OCEAN
BRITISH ISLES
EUROPE
UNION OF SOVIET SOCIALIST REPUBLICS
ASIA MINOR
AFRICA
INDIA
CHINA
JAPAN
PACIFIC OCEAN
INDIAN OCEAN
EAST INDIES
NEW GUINEA
AUSTRALIA
0.5
1
1.5
2
2.5
3
120
100
80
60
40
20
0
20
40
60
80
100
120
140
160
40
20
0
20
40

NOTE

ISOHYETS REPRESENTS INCHES OF MAXIMUM RAINFALL IN ONE HOUR FOR STORM OF 2-YEAR FREQUENCY

Figure 2-5. World isohyetal map.

made to confirm the map study. The following four-step procedure is then used:

(1) Locate existing or proposed structures.

(2) Locate high points.

(3) Draw flow arrows away from high points. (Flow arrows must be perpendicular to contour lines.)

(4) Draw in delineation lines. (Flow arrows cannot cross delineation lines.) The delineation line marks the boundaries of the drainage area, or the drainage basin. Since water always flows downhill, it flows away from highpoints. If all the highpoints are connected by a line, the line formed is the delineation line. Figures 2-6 through 2-12 illustrate flow arrows and delineation lines on several terrain types.

b. When the drainage area has been delineated, the area that lies inside the delineation line can be determined. This can be done by any appropriate method, such as using a planimeter if available, dividing the area into calculable geometric shapes, or by use of the stripper method as illustrated in figure 2-13.

c. In order to determine the other variables of the equation, it will be necessary to determine whether the area is simple or complex. The requirements of this determination have been covered in paragraph 2-7. In the event the area is complex it will also be necessary to define and determine the area of each part of the complex area.

2-10. RATIONAL METHOD SUMMARY

a. Detail needed. The rational method is reasonably simple to use if it is performed methodically so that all the known and variable conditions, as discussed, are covered in detail. Following is a summary outline of the method, with each step listed and numbered in order. If this summary is followed the procedure will be correct and the results obtained will vary only according to the judgments made.

b. Summary outline steps.

(1) Known:

(a) Location.

(b) Soil.

(c) Cover.

(d) Design Life — 2 years (unless otherwise specified)

Determine area in acres "A".

(2) Area type.

(a) Simple — 1 type cover or soil $\geq$ 80% of total area.

(b) Complex — no single type cover or soil $\geq$ 80% of total area.

(3) Establish representative flow paths.

(a) Overland (sheet) flow 200′ (unless observed or stated otherwise).

(b) Ditch-type flow.

Determine Rainfall Intensity in Inches/Hour — "I".

(4) Determine TOC for each flow path (TOC depends on cover, length of path, slope).

Select Maximum TOC

Duration = Maximum TOC

(5) Obtain 2-yr. 1-hr. intensity (isohyetal map)

(6) Obtain "I" for Duration established (Step 4)

Determine Runoff Coefficient — "C"

(7) Select "C" assumed — use higher value from table ("C" depends on cover, soil, slope).

(8) Slope corrections.

(a) Simple AREA — determine Avg Slope

$S_{avg} \geq 2\%$ $C_{corr} = (S_{avg} - 2)0.01 + C_{assumed}$

$S_{avg} \geq 2\%$ No correction

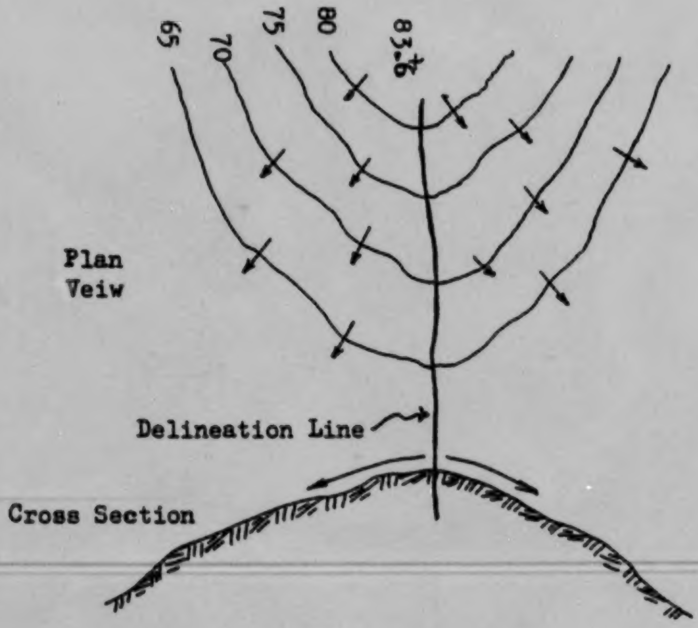

83.6
80
75
70
65
Plan Veiw
Delineation Line
Cross Section

Figure 2-6. Delineation of a hill.

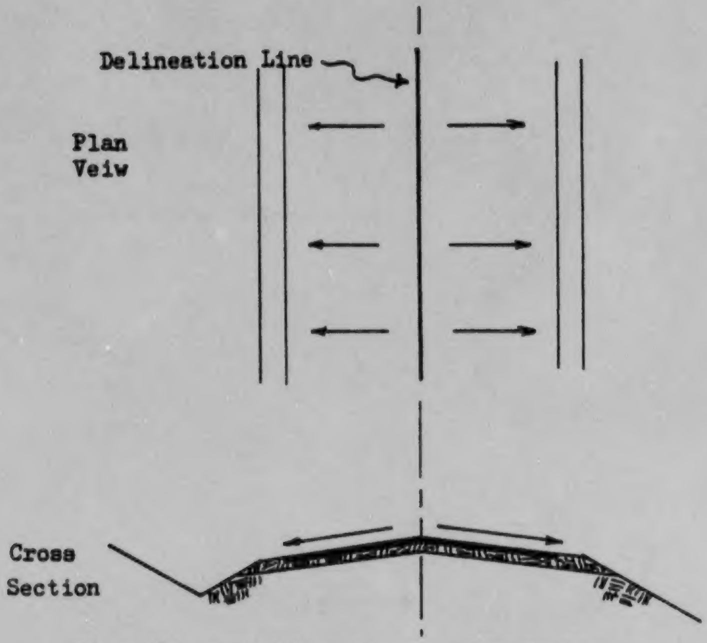

Delineation Line
Plan Veiw
Cross Section

Figure 2-7. Delineation of roads and airfields.

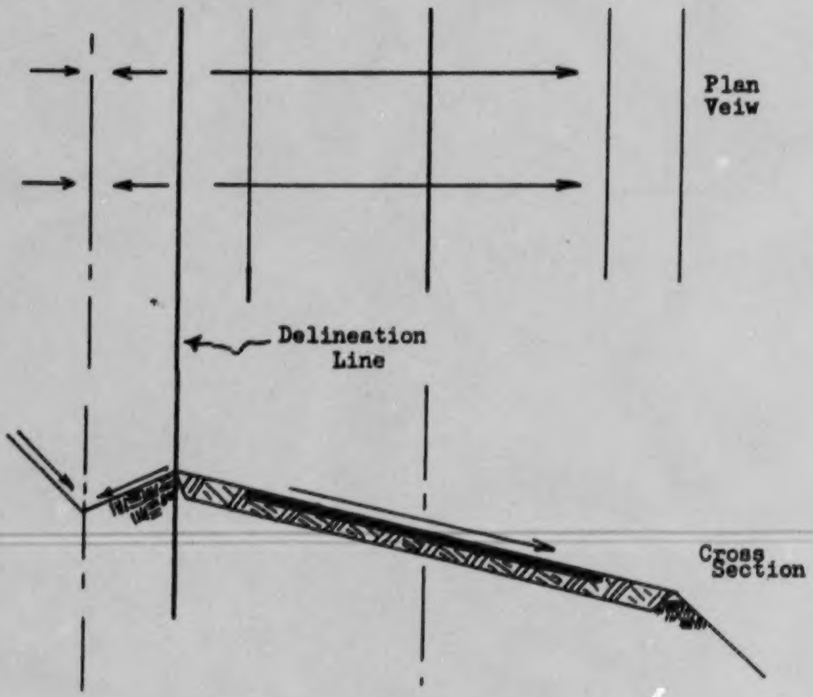

Plan
Veiw
Delineation
Line
Cross
Section

Figure 2-8. Delineation of superelevated road.

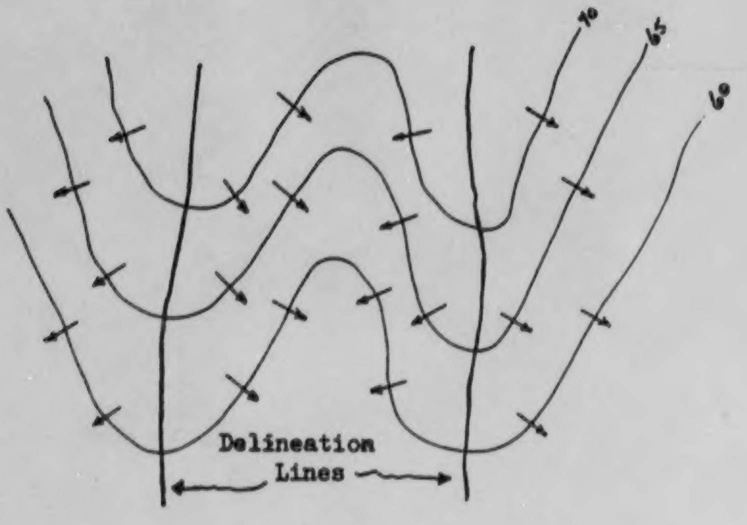

70
65
60
Delineation
Lines

Figure 2-9. Delineation of ridges.

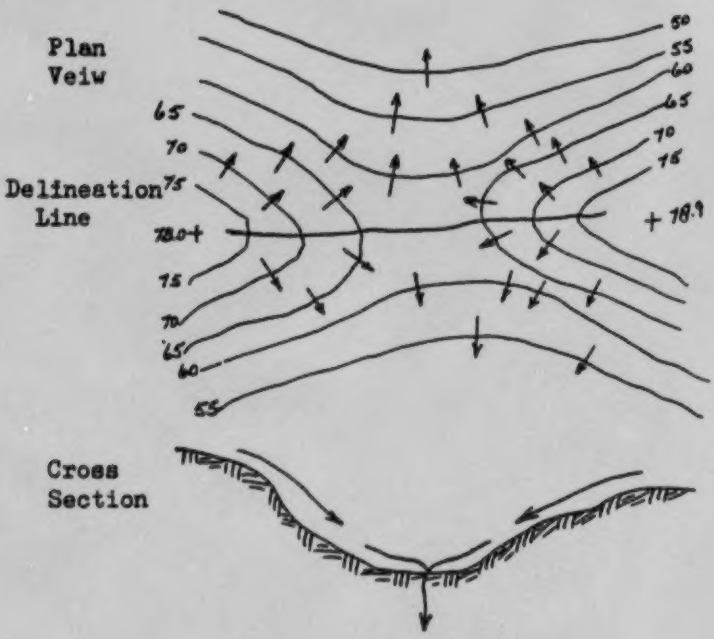

Plan
Veiw
50
55
60
65
65
70
70
75
75
Delineation
Line
78.0+
+ 78.9
75
70
65
60
55
Cross
Section

Figure 2-10. Delineation of a saddle.

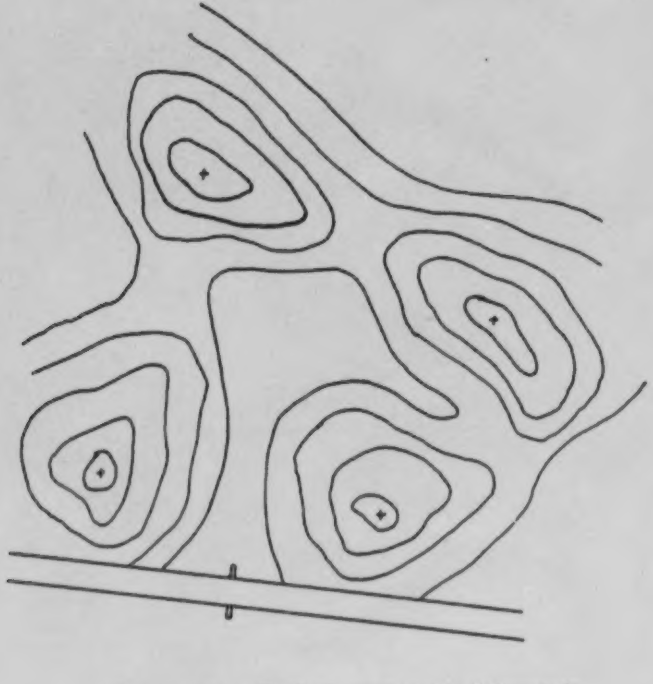


Figure 2-11. Typical area to be delineated.

42

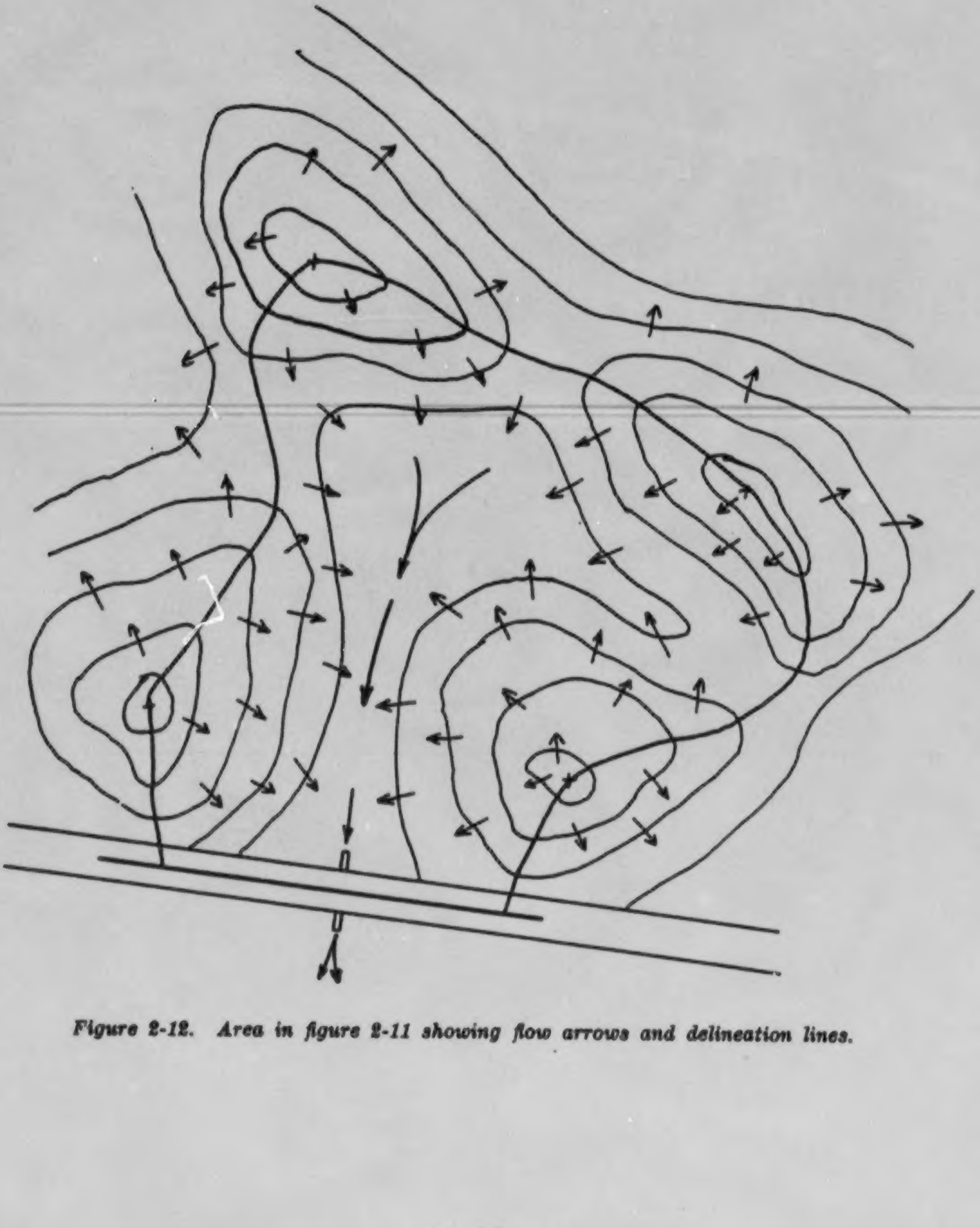
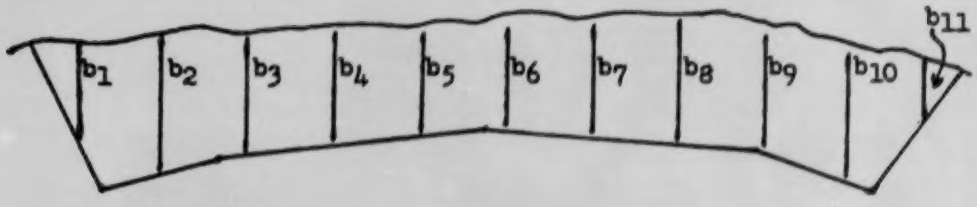
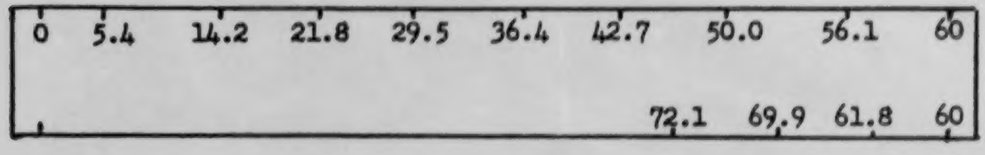


Figure 2-12. Area in figure 2-11 showing flow arrows and delineation lines.

50


b1
b2
b3
b4
b5
b6
b7
b8
b9
b10
b11

STRIPPER UPON COMPLETION


0
5.4
14.2
21.8
29.5
36.4
42.7
50.0
56.1
60
72.1
69.9
61.8
60

NOTE: The stipper method is a variation of the trapezoidal method. If vertical lines are drawn at equal distances "W" apart, then by the trapezoidal formual, the end area "A" will be given by the following:

$$A = \tfrac{1}{2}b_1W + \tfrac{1}{2}(b_1 + b_2)W + \tfrac{1}{2}(b_2 + b_3)W + \tfrac{1}{2}(b_3 + b_4)W + \tfrac{1}{2}(b_4 + b_5)W$$
$$+ \tfrac{1}{2}(b_5 + b_6)W + \tfrac{1}{2}(b_6 + b_7)W + \tfrac{1}{2}(b_7 + b_8)W + \tfrac{1}{2}(b_8 + b_9)W$$
$$+ \tfrac{1}{2}(b_9 + b_{10})W + \tfrac{1}{2}(b_{10} + b_{11})W + \tfrac{1}{2}b_{11}W =$$
$$\tfrac{1}{2}W(2b_1 + 2b_2 + 2b_3 + 2b_4 \ldots\ldots\ldots + 2b_{11}) = W(\Sigma b)$$

Figure 2-13. Stripper method of area determination.

(b) Complex AREA — Determine Avg Slope for EACH SUBAREA: Correct "C" for each SUBAREA that has $S_{avg} > 2\%$. $C_{corr} = (S_{avg} - 2)\ 0.01 + C_{assumed}$

(9) Weighted "C".

(a) Simple AREA — Do not weight C

(b) Complex AREA

$$\text{"C"}_{wt} = \frac{C_1A_1 + C_2A_2 + C_3A_3 + \text{——}}{A_1 + A_2 + A_3 + \text{——}}$$

Note: "C" must be corrected, if needed, before it can be weighted.

(10) Q = CIA

2-11. EXAMPLE PROBLEMS

a. **Simple area problem.** It is required to determine the runoff from the area as shown in figure 2-14. The known conditions will be as stated and as shown on the area map. The solution will be given in a step-by-step procedure covering each item in full detail.

(1) **Known:**

(a) **Location:** Livorno, Italy.

(b) **Soil type:** GMd.

(c) **Cover:**

Average Turf	= 47.9 acres
Compacted gravel	= 0.9 acres
Total	48.8 acres

(d) **Design Life** — 2 yrs.

(2) **Area type.**

$$\frac{47.9 \text{ acres}}{48.8 \text{ acres}} = 98\% > 80\%; \text{ therefore}$$

the area is a simple area.

(3) **Establish representative flow lines.** (See figure 2-14.) Looking at the area, it can be seen that water will flow off the hill masses into the swale section that runs between culverts #7 and #5. The major portion of the eastern hill mass should be contributing water to the outlet by the time a drop of water, traveling along path #1, reaches the outlet. The majority of the western hill mass should be contributing water to the outlet point by the time a drop of water along path #2 reaches the outlet. (Note: Only two flow paths have been drawn on the map for the area. This was done in order to keep the diagrams from becoming cluttered and confusing.) When the flow lines are established, the length of sheet flow is determined, and the remainder of the flow is considered ditch type. The slope of the line segment representing each type of flow is determined.

Path #1

$$\text{Slope 1A} = \frac{95' - 82'}{200'} = 6.5\%$$

$$\text{Slope 1B} = \frac{82' - 52.5'}{1600'} = 1.8\%$$

Path #2

$$\text{Slope 2A} = \frac{92' - 77'}{200'} = 7.5\%$$

$$\text{Slope 2B} = \frac{77' - 52.5'}{1390'} = 1.7\%$$

(4) Determine TOC and duration.

Path	Cover	Slope	Length	Time
1A	Average turf	6.5%	200'	8.5 min
1B	Ditch type	1.8%	1600'	14.5 min
	Total			23.0 min
2A	Average turf	7.5%	200'	8.0 min
2B	Ditch type	1.7%	1390'	14.0 min
	Total			22.0 min

(Times established by using overland flow chart, figure 2-4.)

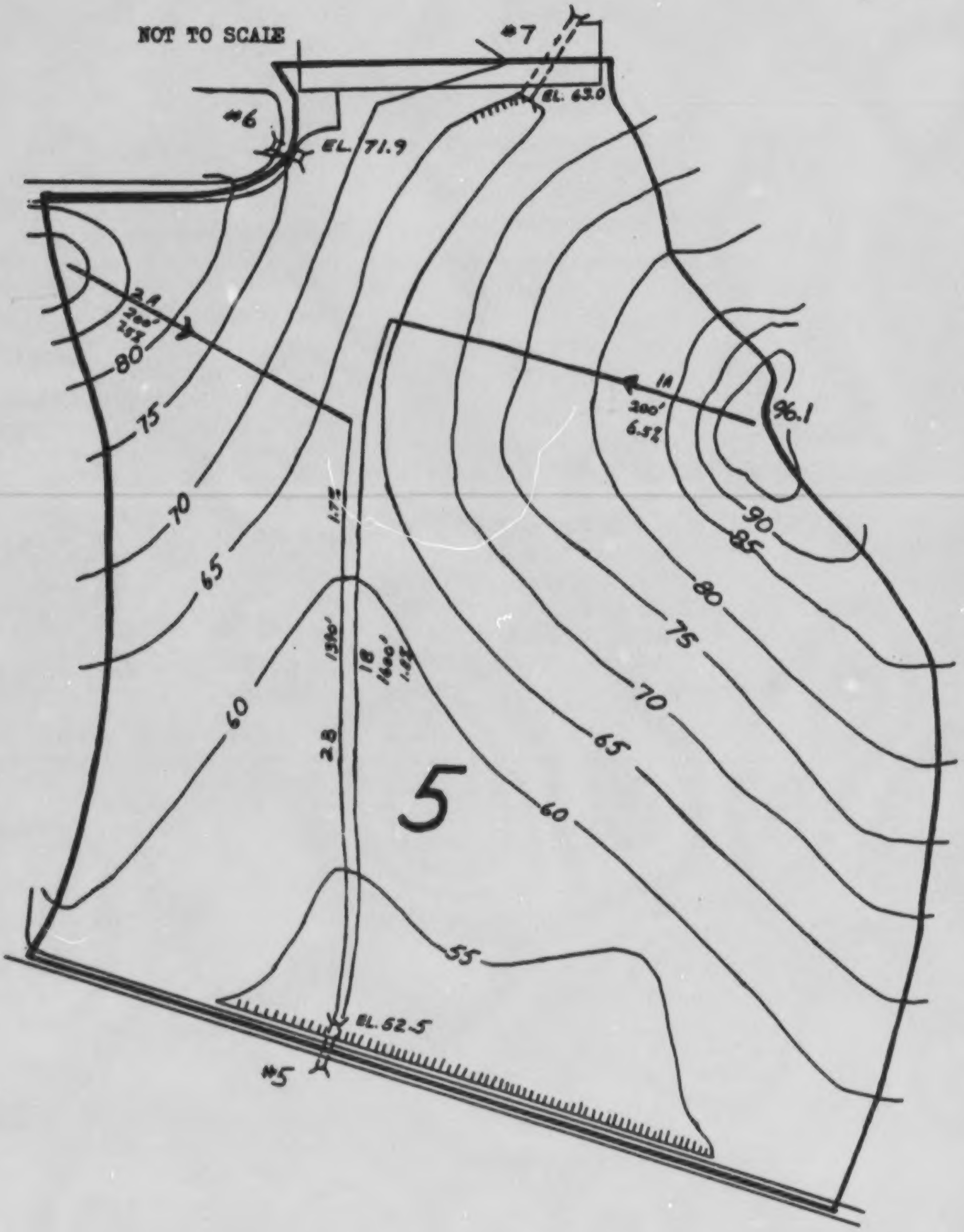

NOT TO SCALE
#7
EL. 63.0
#6
EL. 71.9
2A
200'
2.5%
80
75
70
65
60
1A
200'
6.5%
96.1
90
85
80
75
70
65
60
1.7%
1390'
1B
1400'
1.8%
2B
5
55
EL. 52.5
#5

Figure 2-14. Example problem area 1.

Since the times are relatively close together, and the paths correspond to water coming from the majority of the area, we have established the approximate area TOC. Select the longest time of the representative flow lines as the TOC for the area. In this case, the **area TOC is 23 minutes.** The storm **duration** that will determine the intensity "I" to be used in the equation is 23 min.

(5) **Determine 1-hr 2-yr storm intensity.** The location is Livorno, Italy. Checking the isohyetal map, figure 2-5, we find that 1.5 in/hr is the intensity of a 1-hr, 2-yr storm in Italy.

(6) **Obtain "I" for duration established.** The duration of the critical storm is 23 minutes, as established in Step (4) above. Using the duration intensity curves, figure 1-5, lesson 1, we find that an area where the maximum 1-hr, 2-yr intensity is 1.5 in/hr can expect a storm of 23-minutes duration to have an intensity of approximately 2.9 in/hr (this 2.9 in/hr is the value of "I" in the equation Q = CIA).

(7) **Select "C" assumed.** Since it was determined in Step (2) that the area was a **simple area,** only one "C" value need be determined, i.e., the "C" value of a GMd soil with turf. Table 2-2 gives a "C" assumed value of 0.30 for "slightly pervious soils with turf."

(8) **Slope corrections.** Step 1 determined that the area was a simple area; therefore only one average slope needs to be determined, i.e., the average slope of the entire area. By looking at the area, it can be determined that the area can be divided into 2 parts, with the swale section acting as a dividing line. The area to the west of the swale is approximately ⅓ of the total area, while ⅔ lies to the east of the swale. This indicates that for each slope line placed on the west side, two (2) slope lines should be placed on the east side. (See fig 2-15.) The east side has two distinct slopes: fairly steep in the north, and relatively flat and gentle in the south. Consequently, two separate slope lines are drawn, one in the northern sector and another in the southern sector. On the west side, only one slope line is drawn, so that the proportion of 1:2 is kept. Since only one slope line is put on the west side, it must be placed in such a manner that it approximates the average slope of the entire west side. An alternative solution would be to place two slope lines on the west side, and four on the east side. This keeps the approximate 2:1 proportion, and yields a more accurate average slope. The three slope lines that are placed in figure 2-15 are a result of several placed over the entire area. These three very closely approximate the average area slope, and more were not drawn so that the figure was as simple and uncluttered as possible.

$$\text{Average Slope} = \frac{5.7 + 5.2 + 3.6}{3} = \frac{14.5}{3}$$

$= 4.83\%$

use $4.8\% > 2\%$, therefore "C" must be corrected.

"C" corr = $(4.8 - 2)\ 0.01 + 0.3 = 0.328$
use .33

(9) **"C" weighted.** The area is a simple area; therefore it is not required to weight "C".

(10) Q = CIA

"C" = 0.33 (Step 9)

"I" = 2.9 in/hr (Step 6)

"A" = 48.8 acres (Step 1)

Q = (0.33) (2.9 in/hr) (48.8 acres) = 46.7 cfs use 47 cfs

b. **Complex area problem.** It is required to determine the runoff from the area as shown in figure 2-16. The area as shown comprises a portion of a runway and taxiway with a median turf area. The solution is given in a step-by-step procedure in the same order as given by the summary, paragraph 2-10, and the simple area problem.

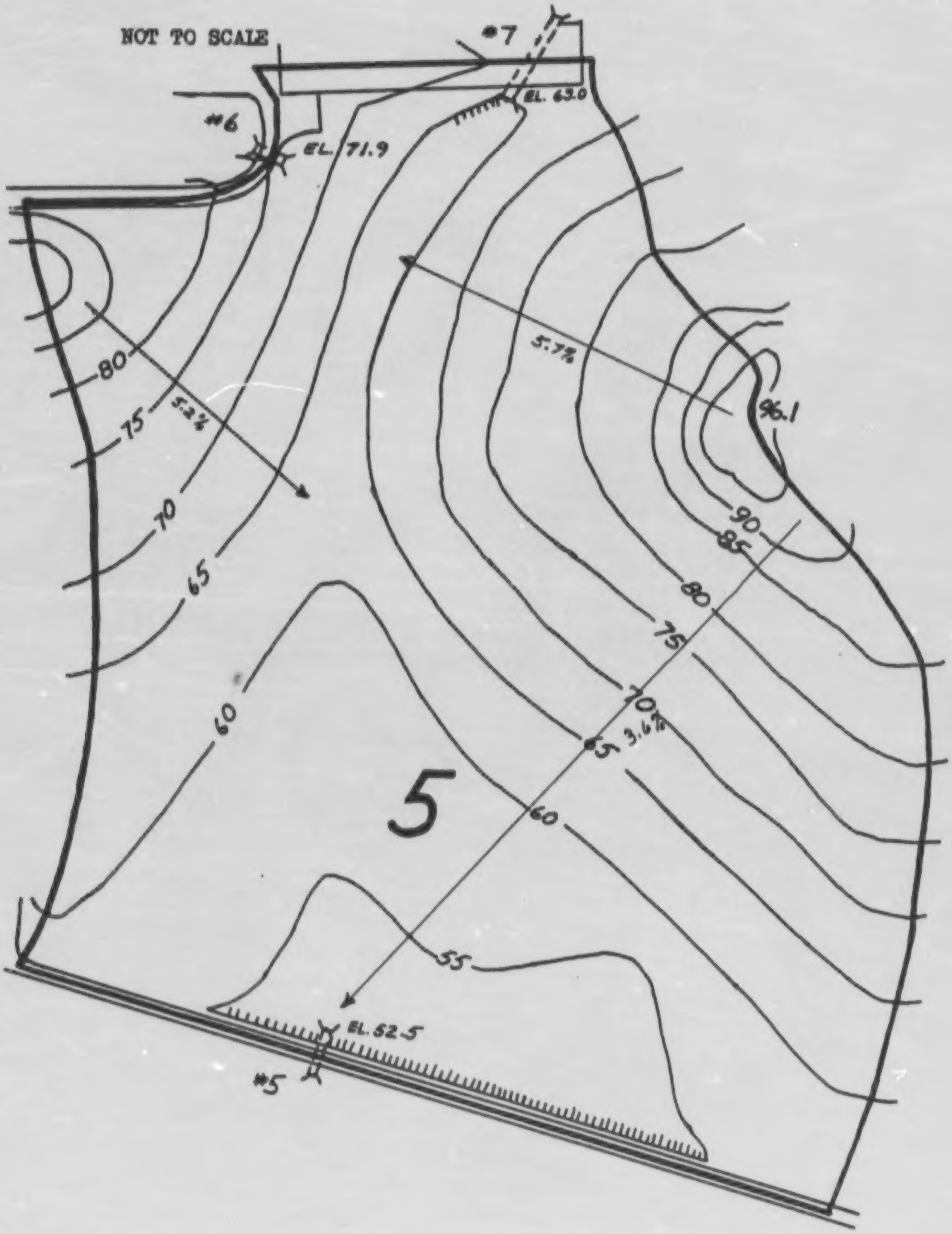

NOT TO SCALE
#7
EL. 63.0
#6
EL. 71.9
80
75
5.2%
70
65
60
5.7%
96.1
90
85
80
75
70
3.6%
65
60
5
55
EL. 52.5
#5

Figure 2-15. Determination of slope lines.

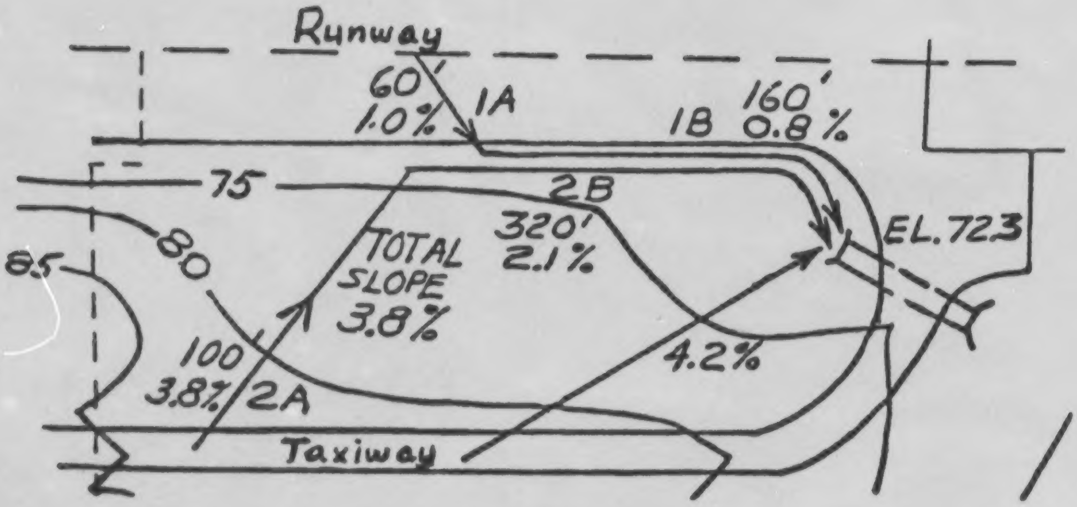

Runway
60'
1.0%
1A
160'
1B 0.8%
75
2B
320'
2.1%
EL. 72.3
85
80
TOTAL
SLOPE
3.8%
100
3.8%
2A
4.2%
Taxiway

Figure 2-16. Example problem area II.

(1) Known
1. Livorno, Italy
2. Soil type — GMd
3. Area — Average turf = 1.5 acres
   Compacted gravel = 0.5 acres
   TOTAL 2.0 acres
4. Design life = 2 years

(2) Average turf $= \frac{1.5 \times 100}{2.0} = 75\% < 80\%$

∴ The area is complex.

(3) Representative flow paths:

Path	Cover/type	L	S%	TOC
1A	Compacted gravel	60	1.0	7
1B	Ditch	160	0.8	8
				15
2A	Average turf	100	3.8	10
2B	Ditch	320	2.1	8
				18 min

(4) TOC for the area is the maximum of 18 minutes.

(5)(6) **Intensity of rain.** Livorno, Italy is within the 1.5 isohyetal line. Reference to the 1.5 curve and with a storm time of 18 minutes will give an area intensity of 3.2 inches/hour.

(7) **Value of C.** The area is complex. Therefore, all values of C will be considered and area C will be a weighted C.

Compacted Gravel C = 0.35 - 0.70 use 0.70

GMd Soil - Average Turf C = 0.30

(8) **Slope correction.** Compacted gravel slopes less than 2%. Therefore, no slope correction and C = 0.7.

Turf area has slopes greater than 2%. Therefore, C must be corrected.

$$\text{Average Slope} = \frac{3.8 + 4.2}{2} = 4.0\%$$

$$C_{corr} = (S_{av} - 2)\ 0.01 + C = (4 - 2)\ .01 + 0.3 = 0.32$$

(9) **Weighted C.**

$$C_{wtd} = \frac{A_1C_1 + A_2C_2}{A_1 + A_2} = \frac{1.5(0.32) + 0.5(0.7)}{2}$$

$$= \frac{0.48 + 0.35}{2} = \frac{0.83}{2} = 0.42$$

(10) $Q = CIA$

$$Q = 0.42(2.0)3.2 = 2.69 \text{ cfs}$$

2-12. SUCCESSIVE AREAS

a. **Theory of successive areas.** Up to this point the drainage areas discussed have been single areas, either simple or complex. Some drainage systems will, however, consist of a series of areas each of which discharges into the lower area. Due to this action the runoff accumulates and increases in its passage through the system. The increase in runoff is not the summation of the peak runoff of each individual area but is an increase modified by various factors. The major factor is the decreasing intensity of the storm effect on the lower areas due to the increasing value of the TOC, this TOC being taken from the outermost watershed boundary to the outlet in question.

b. **Technique of successive areas.**

(1) The purpose of the method is to determine the peak runoff to be expected at each outlet in the sequence of areas. For example consider the sequence of areas shown in figure 2-17.

(a) Peak runoff at outlet #1. The peak runoff (Q) for area #1 at outlet #1 will depend upon the C, I and A of the area, the I being a function of the area TOC.

(b) Peak runoff at outlet #2.

1. For the purpose of this subcourse the following method will be applicable for determining the peak runoff for all succeeding outlets.

2. The Q at outlet #2 is equal to the Q from outlet #1 plus the Q from area #2, i.e., expressed mathematically — Q outlet #2 = $Q_1 + Q_2$. The Q from area #2 is based upon the area acreage, the value of C and the I based upon the largest TOC. This TOC is found by comparison between the area #2 TOC and the TOC of area #1 plus the time it takes the runoff to flow through the culvert and channel to culvert #2. The times are based upon 5 ft/sec in the culvert and 3 ft/sec in the channel.

(c) Peak runoff at outlet #3. The runoff at outlet #3 is equal to the Q from outlet #2 (as obtained from subparagraph (a) above) plus the Q from area #3, mathematically Q outlet #3 = Q outlet #2 = Q area #3. The Q from area #3 is again based upon the largest TOC between the area #3 TOC and the TOC as determined for area #2 plus the flow time in culvert and channel.

(d) Peak runoff at outlet #4. The peak runoff at outlet #4 and each successive outlet is similar to the above sections.

(2) For further illustration of the method, consider figure 2-18. For this example it is assumed the culvert flow time is

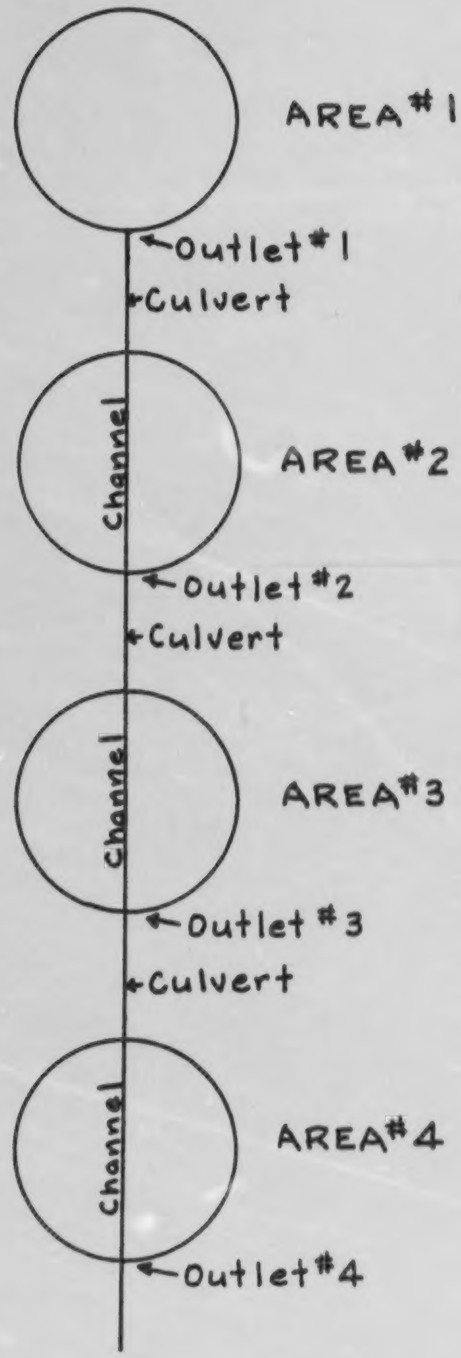


Figure 2-17. Successive areas example 1.

negligible and the ditch time and each area TOC are as noted.

(3) Further examples are shown in figures 2-18 and 2-20 to illustrate the variations that may exist in a succession of areas. The same assumptions will be made as in the previous subparagraph (2).

c. **Summary of successive areas.** Subparagraphs a and b of this paragraph on successive areas have been mainly concerned with the pictorial representation of the technique. In this subparagraph there will be presented a summary of the actions to be taken in computing the runoff from successive areas as follows:

(1) Delineate the drainage basins for each particular outlet.

(2) Determine the following date for area TOC:

(a) Establish representative flow lines.

(b) Obtain TOC for each area.

(c) Obtain flow time between areas.

1. Flow in culvert allow 5 ft/sec = 300 ft/min.

2. Flow in channels allow 3 ft/sec = 180 ft/min.

(3) Route the flow through the areas to obtain the maximum TOC for the inlet under consideration.

(4) Compute the value of C for each area. The value of C should be corrected for slope if necessary and weighted if required.

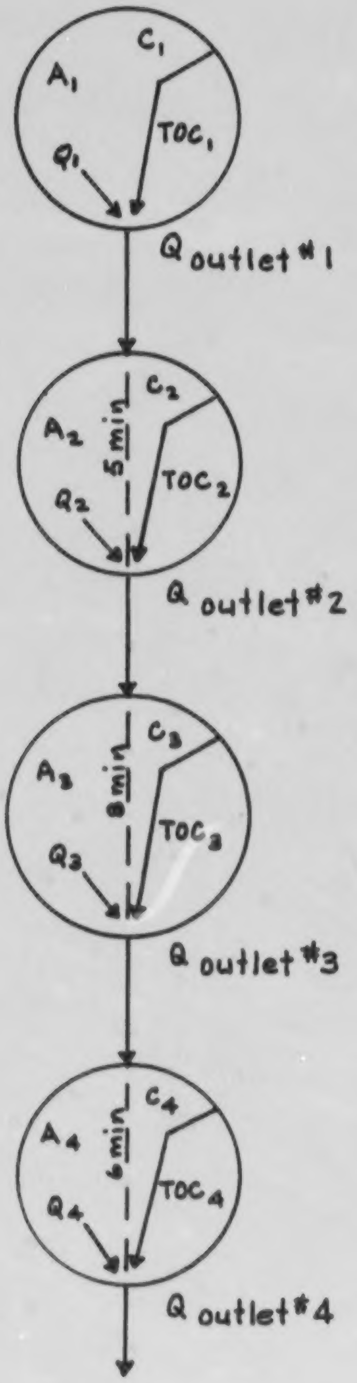
(5) Obtain the rainfall intensity "I" using the TOC found to be maximum.

(6) Compute tributary area "A".

(7) Compute the runoff for each area Q = CIA.

(8) Sum runoff for each area to get the total Q at the outlet under consideration.

d. It is recommended that the results be tabulated when performing the calculations for each successive area. By this pro-


C₁
A₁
TOC₁
Q₁
Q outlet #1
C₂
A₂
5 min
TOC₂
Q₂
Q outlet #2
C₃
A₃
8 min
TOC₃
Q₃
Q outlet #3
C₄
A₄
6 min
TOC₄
Q₄
Q outlet #4

$TOC = 30$

$Q_1 \Rightarrow TOC_{30}, C_1, A_1$

$Q_{outlet\ 1} = Q_1$

$TOC_{outlet\ 1\text{-}2} = 30 + DT = 30 + 5 = 35$

$TOC_2 = 30$

$TOC_{area\ 2} = 35$

$Q_2 \Rightarrow TOC_{35}, C_2, A_2$

$Q_{outlet\ 2} = Q_1 + Q_2$

$TOC_{outlet\ 2\text{-}3} = 35 + DT = 35 + 8 = 43$

$TOC_3 = 45$

$TOC_{area\ 3} = 45$

$Q_3 \Rightarrow TOC_{45}, C_3, A_3$

$Q_{outlet\ 3} = Q_1 + Q_2 + Q_3$

$TOC_{outlet\ 3\text{-}4} = 45 + DT = 45 + 6 = 51$

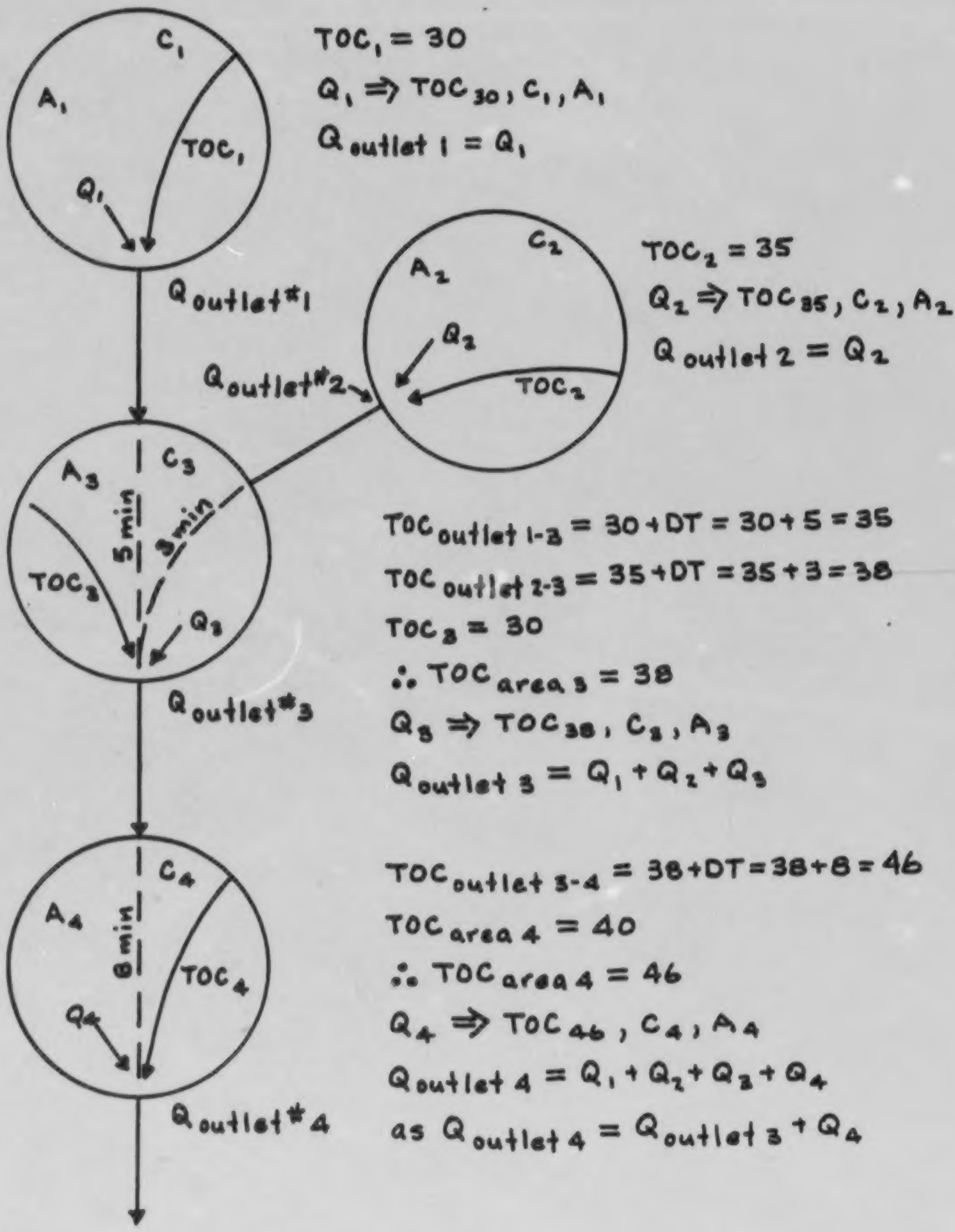
$TOC_4 = 40$

$TOC_{area\ 4} = 51$

$Q_4 \Rightarrow TOC_{51}, C_4, A_4$

$Q_{outlet\ 4} = Q_1 + Q_2 + Q_3 + Q_4$

Figure 2-18. Successive areas example II.


C₁
A₁
TOC₁
Q₁
Q outlet#1
C₂
A₂
Q₂
TOC₂
Q outlet#2
A₃
C₃
5 min
3 min
TOC₃
Q₃
Q outlet#3
C₄
A₄
8 min
TOC₄
Q₄
Q outlet#4

$TOC_1 = 30$

$Q_1 \Rightarrow TOC_{30}, C_1, A_1$

$Q_{outlet\ 1} = Q_1$

$TOC_2 = 35$

$Q_2 \Rightarrow TOC_{35}, C_2, A_2$

$Q_{outlet\ 2} = Q_2$

$TOC_{outlet\ 1\text{-}3} = 30 + DT = 30 + 5 = 35$

$TOC_{outlet\ 2\text{-}3} = 35 + DT = 35 + 3 = 38$

$TOC_3 = 30$

$\therefore TOC_{area\ 3} = 38$

$Q_3 \Rightarrow TOC_{38}, C_3, A_3$

$Q_{outlet\ 3} = Q_1 + Q_2 + Q_3$

$TOC_{outlet\ 3\text{-}4} = 38 + DT = 38 + 8 = 46$

$TOC_{area\ 4} = 40$

$\therefore TOC_{area\ 4} = 46$

$Q_4 \Rightarrow TOC_{46}, C_4, A_4$

$Q_{outlet\ 4} = Q_1 + Q_2 + Q_3 + Q_4$

as $Q_{outlet\ 4} = Q_{outlet\ 3} + Q_4$

Figure 2-19. Successive areas example III.

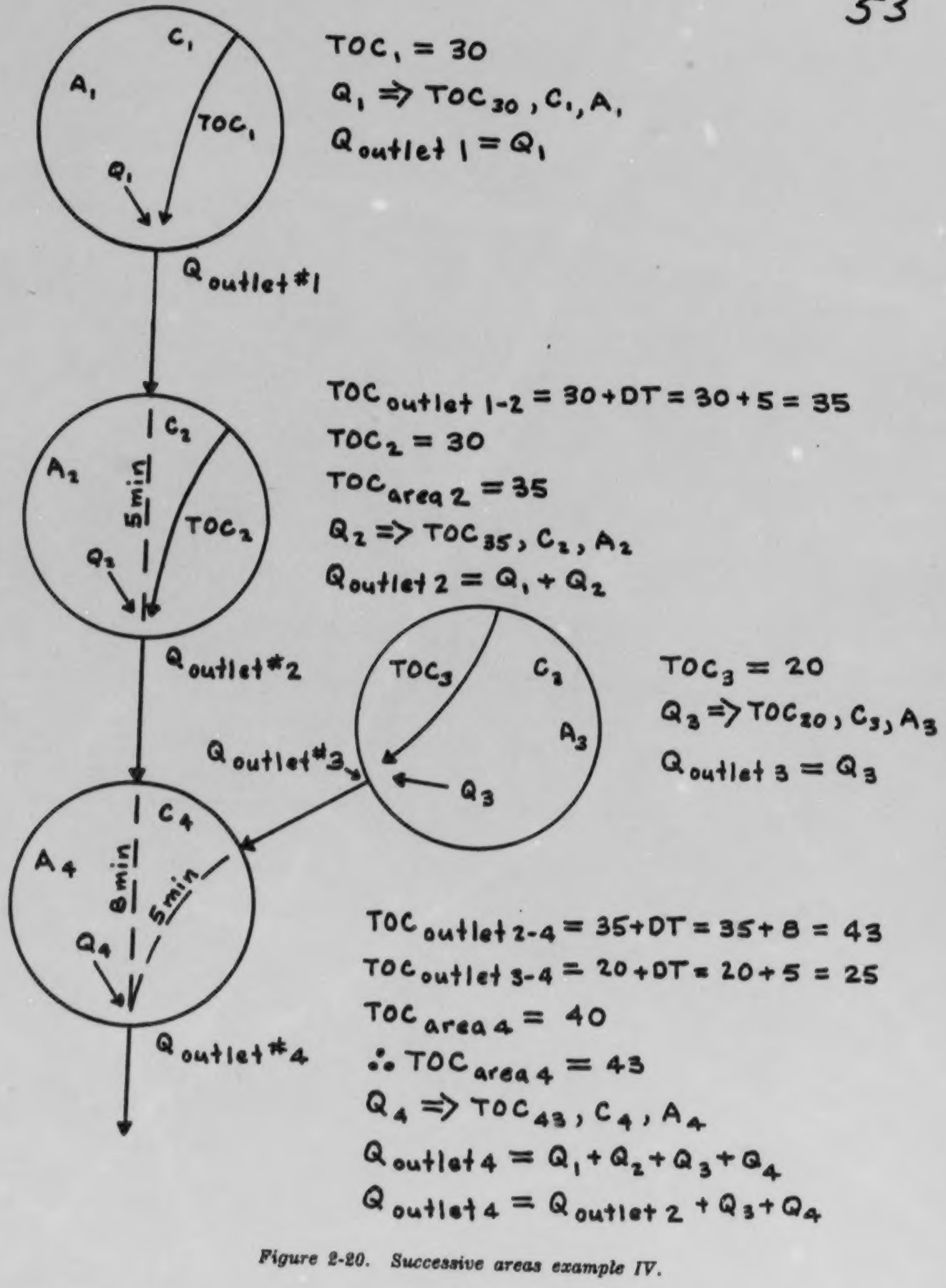

C_1
A_1
TOC_1
Q_1
$TOC_1 = 30$
$Q_1 \Rightarrow TOC_{30}, C_1, A_1$
$Q_{outlet\ 1} = Q_1$
$Q_{outlet\#1}$
C_2
A_2
5min
TOC_2
Q_2
$TOC_{outlet\ 1\text{-}2} = 30 + DT = 30 + 5 = 35$
$TOC_2 = 30$
$TOC_{area\ 2} = 35$
$Q_2 \Rightarrow TOC_{35}, C_2, A_2$
$Q_{outlet\ 2} = Q_1 + Q_2$
$Q_{outlet\#2}$
TOC_3
C_3
A_3
$Q_{outlet\#3}$
Q_3
$TOC_3 = 20$
$Q_3 \Rightarrow TOC_{20}, C_3, A_3$
$Q_{outlet\ 3} = Q_3$
C_4
A_4
8min
5min
Q_4
$Q_{outlet\#4}$
$TOC_{outlet\ 2\text{-}4} = 35 + DT = 35 + 8 = 43$
$TOC_{outlet\ 3\text{-}4} = 20 + DT = 20 + 5 = 25$
$TOC_{area\ 4} = 40$
$\therefore TOC_{area\ 4} = 43$
$Q_4 \Rightarrow TOC_{43}, C_4, A_4$
$Q_{outlet\ 4} = Q_1 + Q_2 + Q_3 + Q_4$
$Q_{outlet\ 4} = Q_{outlet\ 2} + Q_3 + Q_4$

Figure 2-20. Successive areas example IV.

cess, the value of the TOC for each outlet under consideration can be readily determined. Tables 2-4 and 2-5 are presented for use in tabulating the results of the computations. The use of these tables is not mandatory but are presented to indicate the techniques of recording the computation results.

(1) TOC determination table. The items listed on table 2-4 cover the material required to be known in order to determine the TOC of the various areas. In complex areas, the item marked "dist. to inlet" will show for the same inlet two values of sheet (pavement or turf) and ditch flow. The TOC to be selected for further use will be the longest time.

(2) Design data table. The items listed in table 2-5 are as follows:

(a) Item 1 — inlet: The number of the culvert will be given in table 2-4.

(b) Item 2 — line segment: For this item, give the numbers of the culverts between which the channel will run.

TABLE 2-4. *TOC Determination Table*

INLET NUMBER	AREA (ACRES)			DIST. TO INLET (Ft.)				SLOPE (%)			TOC (Min.)			
	PAVEMENT	TURF	TOTAL AREA	PAVEMENT	TURF	DITCH	TOTAL	PAVEMENT	TURF	DITCH	PAVEMENT	TURF	DITCH	TOTAL

TABLE 2-5. *Design Data—Drainage System*

1 INLET	2 LINE SEGMENT	3 LENGTH OF SEGMENT FT	4 INLET TIME MIN	4b FLOW TIME MIN	5 TOTAL TIME MIN	6 TIME OF CONCENTRATION MIN	7 RUNOFF COEFFICIENT "C"	8 RAINFALL INTENSITY "I" IN/HR	9 TRIBUTARY AREA "A" ACRES	10 RUNOFF "Q" CFS	11 ACCUMULATED RUNOFF CFS

(c) Item 3 — length of line segment. The length of the channel between the two culverts.

(d) Item 4 — inlet time. This is the TOC for the particular culvert as taken from table 2-4.

(e) Item 4b — flow time. The time it takes for the flow in the culverts and channels based upon a value of 300 ft/min in culverts and 180 ft/min in channels.

(f) Item 5 — total time. The summation of inlet time and flow time to the particular inlet under consideration.

(g) Item 6 — time of concentration. The time of concentration for a particular inlet is taken as the longest time between the area TOC from table 2-4 and the total time (item 5 table 2-5) from the preceding inlet.

(h) Item 7 — runoff coefficient "C". The C value for the particular area contributing runoff to the inlet. This value is corrected for slope and weighted if required due to the area being complex.

(i) Item 8 — rainfall intensity "I". The intensity of rainfall in ins/hr as determined from the TOC of item 6.

(j) Item 9 — tributary area "A". The total area for the particular inlet as determined from table 2-4.

(k) Item 10 — runoff Q. This is the area runoff as determined from Q = CIA calculated from the values of items 7, 8, and 9.

(l) Item 11 — accumulated runoff. The total quantity of runoff that can be expected at a particular inlet. It is a summation of the accumulated runoff plus the area runoff as given by item 10. Care must be taken to analyze the drainage flow so that proper summation of runoff can be made at the inlet under consideration. With reference as to the above statement, see figures 2-18, 2-19, and 2-20.

2-13. SUCCESSIVE AREA PROBLEM

a. Requirement. It is required to design culverts #1, #2, #3 and #4 as shown on figure 2-21. For design purposes, it will be required to determine the runoff from the areas #1 and #2 and then determine the runoff to the inlets #3 and #4 by the successive area method. For the problem the following information is given.

Area Map — See figure 2-21 — Scale 1" = 200 ft.

Area #1 —

Area: Turf = 14.5 acres

Average Grass Cover

GMd Soil

Invert Elev. Culvert #1 = 44 ft.

Area #2

Area: Asphalt = 4.7 acres

GMd Soil

Invert Elev. Culvert #2 = 31.8 ft

Area #3

Area: Turf = 6.6 acres

Average Grass Cover

GMd Soil

Invert Elev. Culvert #3 = 24 ft

Area #4

Area: Turf = 10.5 acres

Average Grass Cover

GMd Soil

Invert Elev. Culvert #4 = 9 ft.

b. Calculations.

(1) The representative flow lines for each area have been indicated. The same lines, over the slopes, are also indicative of the slope lines for the correction of "C".

(2) Table 2-6 gives the values used in various determinations and the results thereof. Reference is made to the discussion and the illustrated problem given for simple areas, for the type of calculations required, and for solutions of the areas.

(3) The TOC, item 6 Design Data Table, is the area TOC unless other areas

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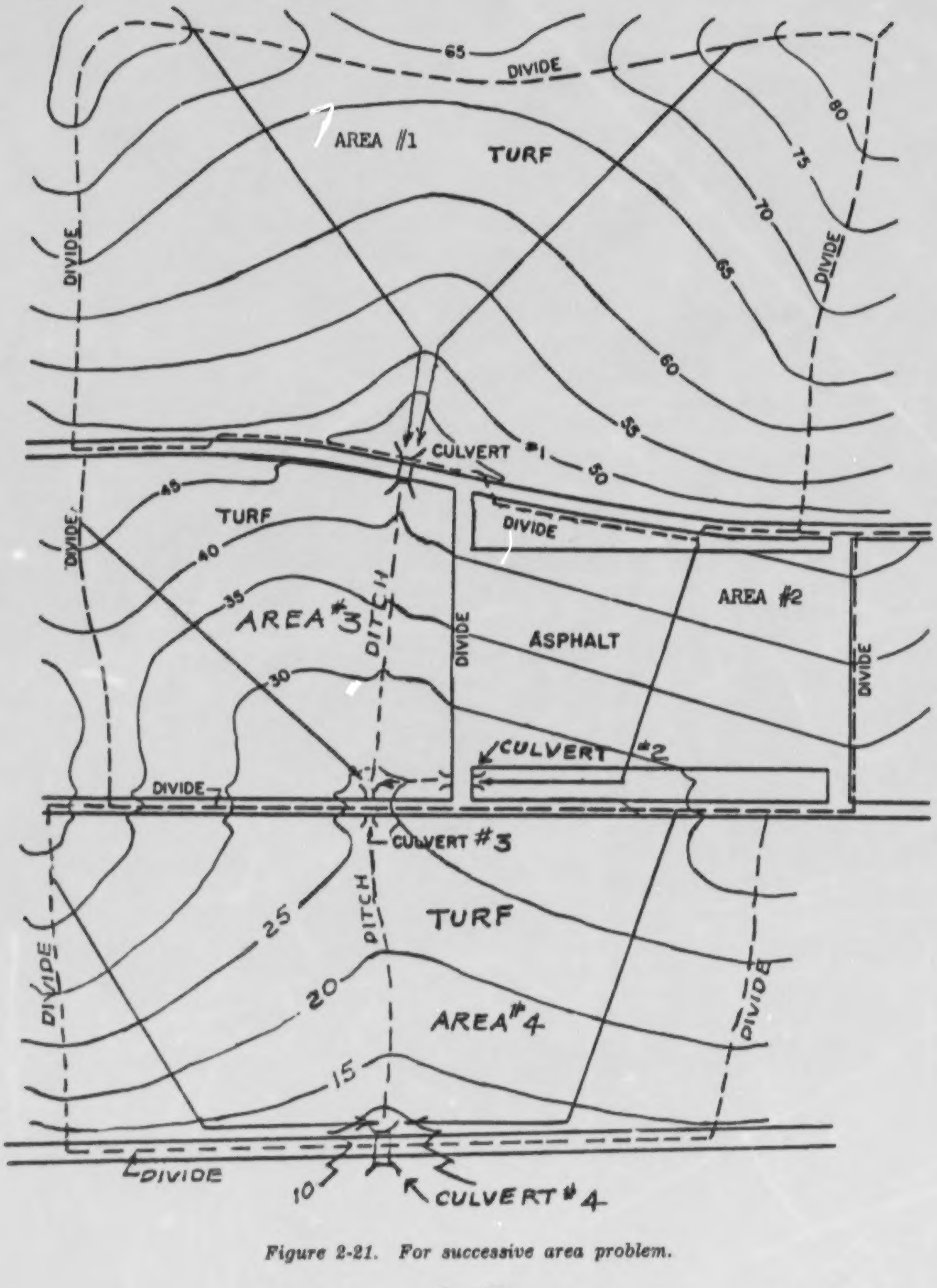

65
DIVIDE
AREA #1
TURF
80
75
70
65
60
55
50
DIVIDE
DIVIDE
CULVERT #1
45
TURF
DIVIDE
40
35
AREA #3
DITCH
DIVIDE
AREA #2
ASPHALT
DIVIDE
30
CULVERT #2
DIVIDE
CULVERT #3
25
DITCH
TURF
20
AREA #4
15
DIVIDE
DIVIDE
DIVIDE
10
CULVERT #4

Figure 2-21. For successive area problem.

TABLE 2-6. ***Calculations for Successive Areas Problems***

INLET NUMBER	AREA (ACRES)			DIST. TO INLET (Ft)				SLOPE (%)			TOC (Min.)			
	PAVEMENT	TURF	TOTAL AREA	PAVEMENT	TURF	DITCH	TOTAL	PAVEMENT	TURF	DITCH	PAVEMENT	TURF	DITCH	TOTAL
1		14.6	14.6		200	500	700		5.5	4.0		10	7	17
					200	550	750		5.5	4.0		10	7	17
2	4.7		4.7	350		200	550	4.6		1.3		6	8	14
3		6.6	6.6		200	370	570		5.0	3.3		9	7	16
4		10.5	10.6		200	450	650		5.5	4.0		9	8	17
					200	500	700		2.5	3.0		16	8	24

TOC DETERMINATION

1	2	3	4	4b	5	6	7	8	9	10	11
INLET	LINE SEGMENT	LENGTH OF SEGMENT FT	INLET TIME MIN	FLOW TIME MIN	TOTAL TIME MIN	TIME OF CONCENTRATION MIN	RUNOFF COEFFICIENT "C"	RAINFALL INTENSITY "I" IN/HR	TRIBUTARY AREA "A" ACRES	RUNOFF "Q" CFS	ACCUMULATED RUNOFF CFS
1	1-3	460	17	2.5	19.5	17.0	0.32	3.2	14.6	15.0	—
2	2-3	150	14	0.8	14.8	14.8	0.98	3.5	4.7	16.0	—
3	3-4	450	16	2.5	18.5	19.5	0.32	3.1	6.6	6.6	37.6
4	—	—	24	—	24.0	24.0	0.33	2.8	10.5	9.7	47.3

DESIGN DATA

are involved, in which case it will be the longest TOC. Referring to inlet #3 it will be observed that the area TOC is 16 min, but for areas #1 and #2, the TOC to inlet #3 is 19.5 and 14.8 min. respectively. In this case, for area #3, the TOC to be used is the largest value under item #5 or 19.5 min. The runoff "Q" for area #3 is then based on this TOC of 19.5 min. For area #4, the TOC to be used will be the largest value between the area TOC and the TOC from the previous #3 inlet, including flow time. In this case, the area TOC is 24 min. (item #4) and the TOC from the previous inlet of 19.5 min. plus the flow time of 2.5 min or 22 min. The TOC to be used for calculating the Q of area #4 is, therefore, 24 minutes.

(4) The runoff "Q" for each area is given in item #10. For area #1, the value of Q is 15 cfs and for area #2 is 16 cfs. Inlet #3 receives the flow from areas #1 and #2 and also the adjusted runoff from its own area #3 or the accumulated value of 37.6. Inlet #4 is taken in a similar manner and the accumulated total is 37.6 cfs plus 9.7 cfs or 47.3 cfs.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space below the question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in the back of this booklet. Do not send in your solutions to these review exercises.

1. Not considering rainfall, what are the three factors which most affect rate and quantity of runoff? (2-2a)

2. In its early stages, runoff is generally in the form of sheet flow. What is normally considered the maximum distance before sheet flow changes to channelized flow? (2-21)

3. Under what circumstances may you use the **hasty method** for calculating the size of drainage structure required? (2-4b)

4. In relation to the rational method for calculating quantity of runoff, what is the definition of a **complex area?** (2-6b(5)(b))

5. In the rational method formula Q = CIA, how would you express mathematically the value of "C"? (2-7)

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6. Why is it necessary to adjust the value of "C" when the average slope of a drainage area exceeds 2%? (2-7b (1))

7. What conditions of soil, cover and/or man-made structures in a drainage area would make it necessary to weight the value of "C"? (2-7c(1))

8. When it is necessary to both correct the value of "C" for slope and weight the value of "C" for soil or turf conditions, which is done first? (2-7c (2))

9. Maximum runoff for a certain rainstorm and a specific drainage area will occur only when what two conditions exist? (2-8a(1))

10. Why is it necessary to determine representative flow paths for a drainage area? (2-8b(1)(a))

11. What is meant by the term "representative flow path?" (2-8b(1) (a))

12. If the 1 hour, 2 year intensity for a rainstorm is 2.2 inches, what is the storm's intensity for 30 minutes? (table 1-5, lesson 1)

13. One section of a flow path is 300 feet overland on average turf with a 6% slope. What is the time of flow for this section? (2-8c(2)(c)(2), fig 2-4)

14. Another section of a flow path is 800 feet in a lined channel on a 1% slope. What is the time of flow for this section? (2-8c(2)(c)(2), fig 2-4)

15. The intensity (I) to be used in the rational method formula, Q = CIA is the intensity of a particular storm for what period of time? (2-8c)

16. How do you determine which of the rainfall intensity-duration curves to use in determining the storm intensity? (2-8c(1))

17. What do you determine to be the one-hour, two-year rainfall intensity for the eastern tip of Brazil? (2-8c (1))

18. A drainage area in the vicinity of Washington, DC has a calculated TOC of 35 minutes. What value would you use for I in the rational method formula? (2-8c(1), (2))

19. What is the reason for establishing delineation lines on a topographic map of the drainage area being studied? (2-9a)

20. Name three methods of measuring the acreage inclosed by an irregular delineation line. (2-9b)

LESSON 2A

SURFACE RUNOFF (TALBOT'S AND OCE METHODS)

CREDIT HOURS	2
TEXT ASSIGNMENT	Attached memorandum.
MATERIALS REQUIRED	Annex A.
LESSON OBJECTIVE	To teach additional methods for calculation of surface runoff.
SUGGESTIONS	Read the attached memorandum through rapidly to obtain a knowledge of its scope. Then read it through carefully, underlining the important points and objectives. Read the review questions at the end of the lesson. Study the lesson, searching for answers to the review questions, and write your answers in the spaces provided. Finally, check your answers with the answers given for this lesson at the back of this booklet. Review as necessary.

ATTACHED MEMORANDUM

Section I. INTRODUCTION

2A-1. GENERAL

The purpose of this lesson is to provide you with sufficient information and detail to apply Talbot's formula and the Corps of Engineers method in the solution of drainage problems.

2A-2. TALBOT'S FORMULA

Talbot's formula provides directly the area of the opening of the drainage structure required without determination of the quantity of runoff water involved.

2A-3. CORPS OF ENGINEERS METHOD

The Corps of Engineers method is a deliberate process involving many factors, tables, and graphs, and results in a rate of runoff for a given drainage area. Recommended uses are included in the detailed discussions of each method.

Section II. TALBOT'S FORMULA

2A-4. INTRODUCTION

Talbot's formula may be used as an approximate method for computing the cross-sectional area of the proposed pipe or culvert. This method is derived from observations made by Professor Talbot, for gently rolling farmland in the midwestern part of the United States.

2A-5. DETAILS

This formula is:

$$A = C \sqrt[4]{D^3}$$

in which A = area of waterway opening in square feet

D = drainage area in acres

C = a coefficient that depends upon the slope, shape, and general character of the area to be drained

This formula is recommended only for small structures requiring a waterway opening of not greater than 400 square feet. In addition, the formula is intended only for a maximum rainfall intensity of 4 inches per hour. For locations having greater intensities than this, the required opening may be computed by dividing the area of the drainage structure obtained from the formula by 4, and multiplying the result by the intensity of rainfall to be expected at the given location. No adjustment is made for a rainfall intensity less than or equal to 4 inches per hour. The accuracy of this formula is dependent on the selection of the coefficient C. Normal values for C are as follows:

C = 0.2 for flat areas not affected by accumulated snow and where the length of the valley drained is several times the width.

C = 0.35 for gently rolling farm land where the length of the valley is about 3 or 4 times the width.

C = 0.7 for rough, hilly areas having moderate slopes.

C = 1.0 for steep, barren areas having abrupt slopes, and for moderately mountainous areas.

The value of the coefficient C is influenced by the shape of the drainage area, the side slopes and the length of the valleys, and by the general character and culture of the ground. All of these factors affect the rate of runoff. Therefore the engineer must adjust the value of C to suit each case. The value of C should be increased as the lengths of the valleys decrease in proportion to the widths, and vice versa. As side slopes steepen, C should be increased. Heavy scrub growth would decrease the value of C as compared with cultivated farm land, whereas rock or barren slopes would increase the value of C. Predominantly sandy or gravelly soils tend to decrease C, whereas heavy clay soils tend to increase C. A value of 1.0 is satisfactory for moderately mountainous terrain, or for reasonably steep barren areas with abrupt slopes of up to 10 percent. The formula should not be used for precipitous, rocky, mountainous areas where C would be greater than one. The drainage areas may be obtained from a map of the area involved, either by planimetering or by dividing the area into several triangles and/or rectangles. Waterway openings for various drainage areas are given in table 2A-1. A nomograph for the solution of Talbot's formula is given in figure 2A-1. The diameter of pipe in feet can be computed by using the formula:

$$\text{Diameter} = \sqrt{\frac{4A}{\pi}}$$

in which A = area of waterway, in square feet.

Example: Drainage area is 200 acres of rolling farm land (C = 0.35)

$$A = 0.35 \sqrt[4]{200^3} = 0.35 \sqrt[4]{(2 \times 10^2)^3}$$

$$= 0.35 \sqrt[4]{8 + 10^6} = 0.35 \sqrt[4]{800 \times 10^4}$$

$$= 0.35 \times 5.32 \times 10 = 18.6 \text{ or } 19 \text{ sq ft}$$

$$A = 19 \text{ sq ft}$$

$$\text{Pipe diameter} = \sqrt{\frac{4 \times 19}{\pi}}$$

$$= \sqrt{24.2} = 4.9 \text{ or } 5 \text{ ft}$$

TABLE 2A-1. *Required Culvert Opening in Square Feet, Computed by Talbot's Formula*

Drainage area in acres	Mountainous (C = 1.0)	Hilly (C = 0.7)	Sharply rolling (C = 0.5)*	Flat (C = 0.2)
2	1.7	1.2	0.9	0.3
5	3.3	2.3	1.7	.7
10	5.6	3.9	2.8	1.1
20	9.5	6.7	4.8	1.9
30	12.8	9.0	6.4	2.6
40	15.9	11.1	8.0	3.2
50	17.8	12.5	8.9	3.6
75	25.4	17.8	12.7	5.1
100	31.6	22.1	15.8	6.3
150	42.9	30.0	21.5	8.6
200	53.1	37.2	26.6	10.7
300	72.2	50.5	36.1	14.4
400	88.1	61.7	44.1	17.6
500	106.0	74.2	53.0	21.2
600	121.0	85.0	61.0	24.0
800	151.0	106.0	76.0	30.0
1,000	178.0	125.0	86.0	36.0
1,200	204.0	143.0	102.0	41.0
1,500	241.0	169.0	121.0	48.0
2,000	299.0	209.0	150.0	60.0
2,500	353.0	247.0	177.0	71.0
3,000		284.0	203.0	81.0
4,000		352.0	252.0	101.0
5,000			298.0	119.0
7,500				161.0
10,000	Formula not to be used for these conditions.			200.0
15,000				271.0
20,000				336.0

*The normal value of C for gently rolling areas is 0.35.

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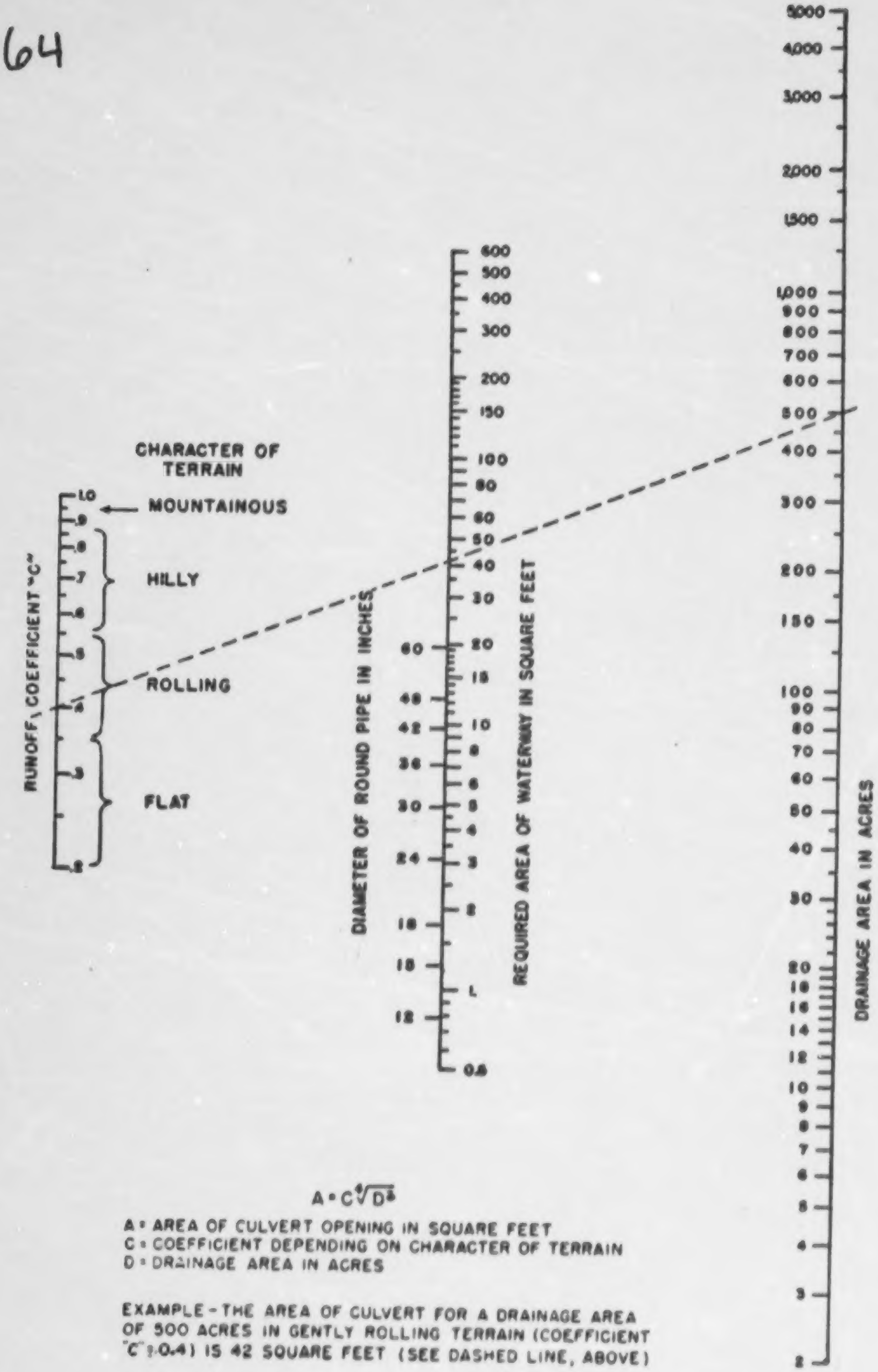


$A = C\sqrt[4]{D^3}$

A = AREA OF CULVERT OPENING IN SQUARE FEET
C = COEFFICIENT DEPENDING ON CHARACTER OF TERRAIN
D = DRAINAGE AREA IN ACRES

EXAMPLE - THE AREA OF CULVERT FOR A DRAINAGE AREA OF 500 ACRES IN GENTLY ROLLING TERRAIN (COEFFICIENT "C" = 0.4) IS 42 SQUARE FEET (SEE DASHED LINE, ABOVE)

Figure 2A-1. Nomograph for solution of Talbot's formula.

Section III. CORPS OF ENGINEERS METHOD

2A-6. DELIBERATE METHOD OF DETERMINING RUNOFF

a. Although the Corps of Engineers deliberate method of estimating runoff, as developed by Hathaway and Horton, is especially applicable to airfields, it can also be used for other construction projects.

Horton's equation is as follows:

$$q = \tanh^2 \sigma \, [0.922 \, t \, (\sigma/nL)^{0.50} S^{0.25}]$$

where q = rate of flow in inches per hour or cubic feet per second per acre of drainage area.

σ = rate of supply or rainfall in excess of the rate of infiltration in inches per hour.

t = time or duration in minutes.

$\tanh^2$ = hyperbolic tangent squared.

n = retardance coefficient.

L = length of flow in feet.

S = slope of surface or hydraulic gradient in feet per foot.

b. A series of tables and graphs have been developed which will be used in solving for q, thus simplifying the computations required to determine the runoff when using this method. A more detailed explanation of the Corps of Engineers method may be found in the TM 5-820 series.

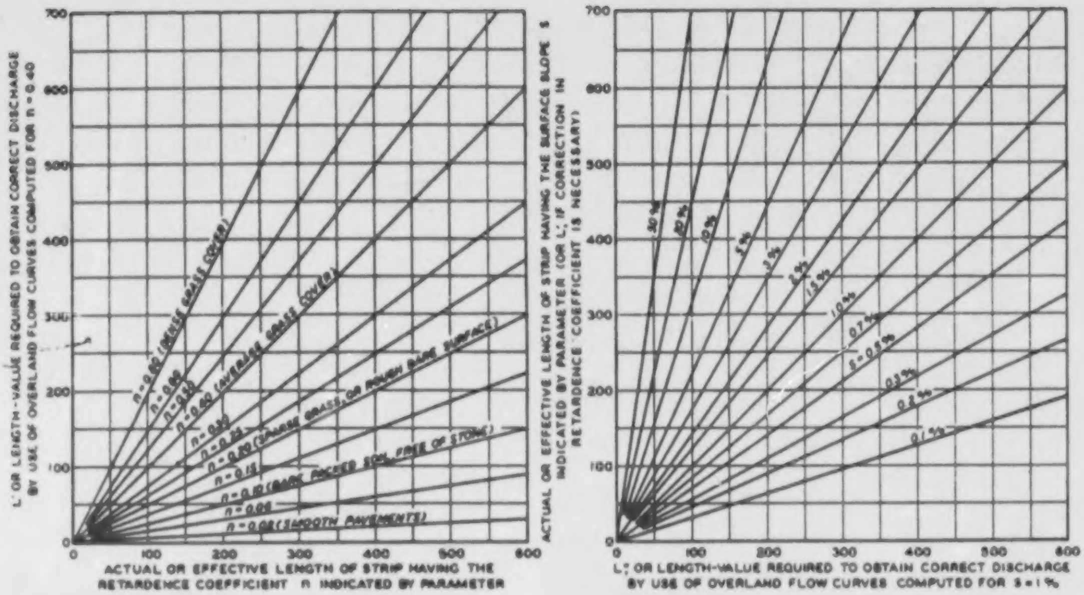
c. Horton's equation was used to compute a series of overland flows vs duration graphs assuming $n = 0.40$ and $S = 1.0$ percent. Each graph is composed of curves based on various rates of supply for a given length and slope of overland flow. These curves may be used for surfaces having other retardance coefficients or surface slopes by using, instead of actual length and slope of the flow involved, an equivalent length which compensates for the difference between the values of n and S used in developing the curves. **Equivalent length** is indicated by the symbol L_E. The equivalent length is the average length of flow, converted to a length equivalent to $n = 0.40$ and $S = 1.0$ percent. Figure 2A-2 can be used to find the L_E.

d. The Corp of Engineers method requires that you select a design storm rainfall. This can be done from local records if sufficient datum is available. Otherwise you can use the United States isohyetal map (fig 2A-3) or the world isohyetal map (fig 2-5, lesson 2).

e. It should be noted that the curves referred to in c above, and shown in figures 2A-4 to 2A-10, inclusive, are not hydrographs for any specific design storm, but represent the peak rates of runoff from individual storms of various durations, all of which have the same average frequency of occurrence. The duration of supply corresponding to the greatest discharge for a particular standard supply curve and given value of L is defined as the critical duration of supply (t_c) for runoff from an area not affected by surface ponding. For a simple area, the length to be used in figures 2A-4 through 2A-10 is the sum of the equivalent lengths of sheet, channelized, and ditch flow. For a complex area, the length to be used in figures 2A-4 through 2A-10 is the weighted equivalent length computed by the equation,

$$\text{Weighted } L_E = \frac{A_1 L_{E_1} + A_2 L_{E_2} + \ldots.}{A_1 + A_2 + \ldots.}$$

where L_{E_1}, L_{E_2} etc. are the equivalent lengths of the surfaced areas (including ditch flow) and turfed areas (including channelized flow and/or ditch flow). For successive areas, the length to be used in figures 2A-4 through 2A-10 is the weighted equivalent length derived from the weighted equivalent lengths of each area, including the equivalent length of additional channelized and/or ditch flow where applicable. The principles stated above may best be understood from the procedure and examples which follow in paragraphs 2A-7 through 2A-10.



A. CORRECTION FOR DIFFERENCES IN RETARDENCE COEFFICIENT (n)

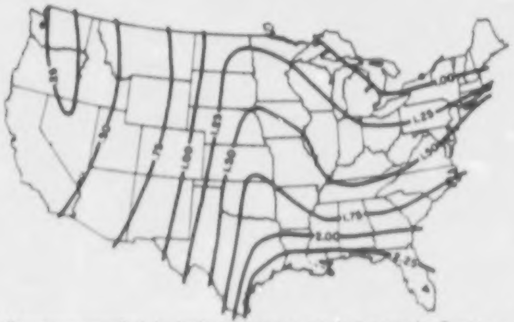
B. CORRECTION FOR DIFFERENCES IN SLOPE (S)

Figure 2A-2. Nomograph for equivalent length.

2A-7. PROCEDURE FOR CORPS OF ENGINEERS METHOD

a. Secure or draft a topographic map of 1:2400 or 1 inch = 200 feet of the area from which the rate of runoff is to be determined.

b. Delineate and subdivide the area into drainage areas and subareas as described in paragraphs 2-2h and 2-9, lesson 2.



One-hour rainfall, in inches, to be expected once in 2 years.

Figure 2A-3. United States isohyetal map.

c. Calculate the size of the drainage areas with respect to the various types of cover.

d. Determine whether the area is simple or complex (para 2-2g, lesson 2).

e. Select representative paths of sheet, channelized, and ditch flow on the map.

f. Measure the horizontal length (L) and compute the slope (S) of each representative path of flow selected.

g. Calculate the average length (L) and average slope (S) of sheet, channelized, and ditch flow.

h. Select a coefficient of retardation "n", table 2-1, lesson 2.

(1) Study the surface of areas and subareas.

(a) Reconnaissance—look for turf, bare ground, etc.

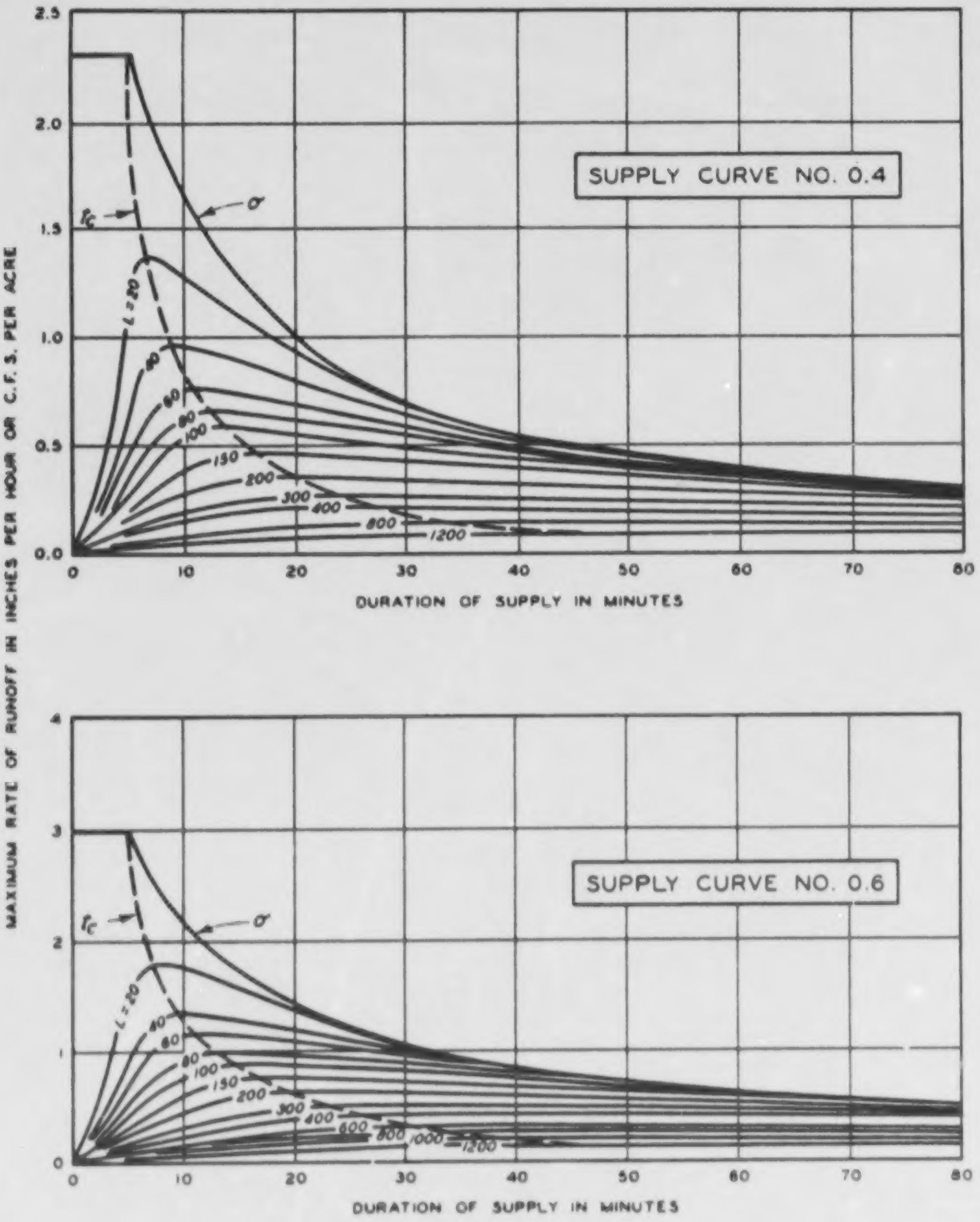


Figure 2A-4. Supply curves.

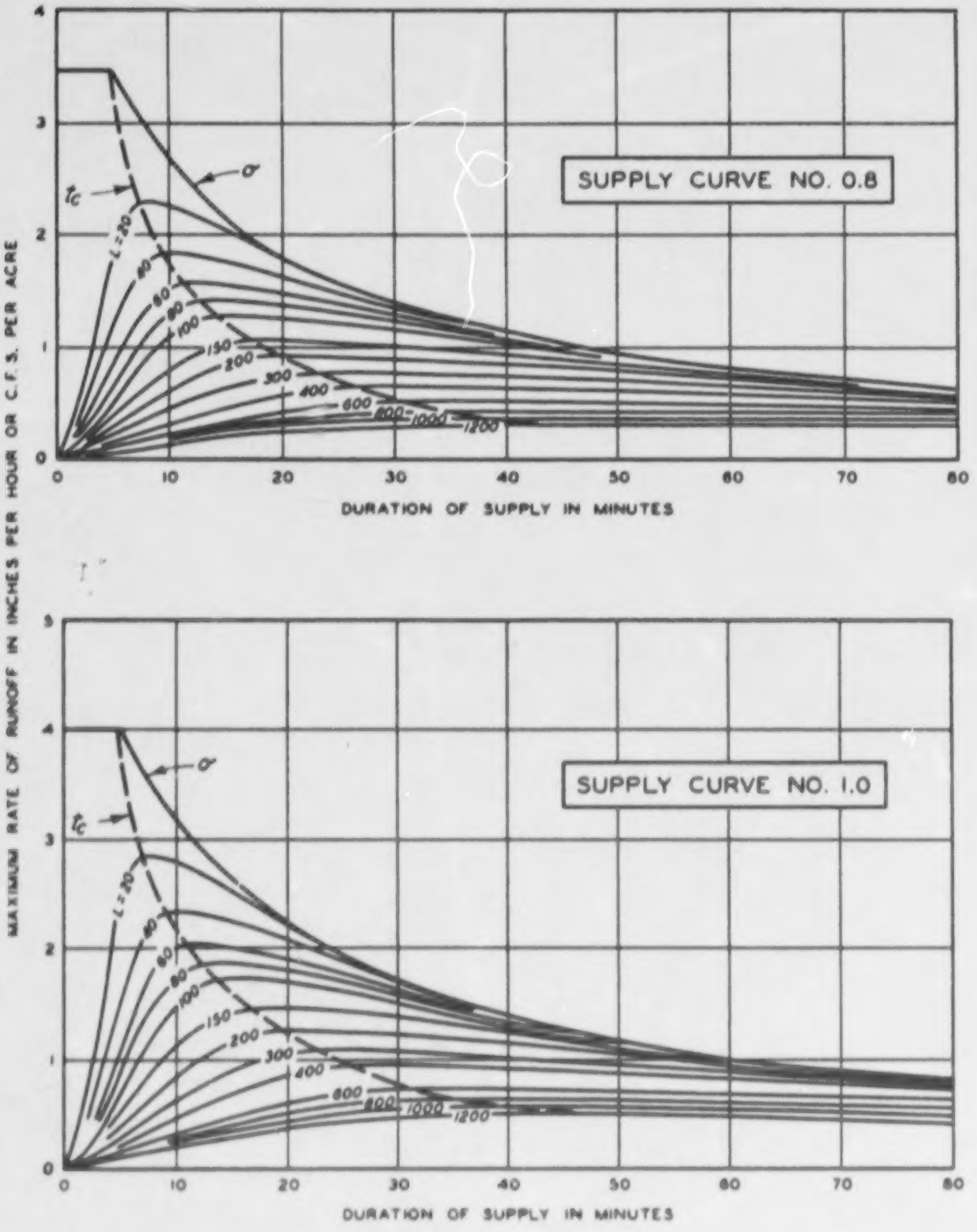


Figure 2A-5. Supply curves.

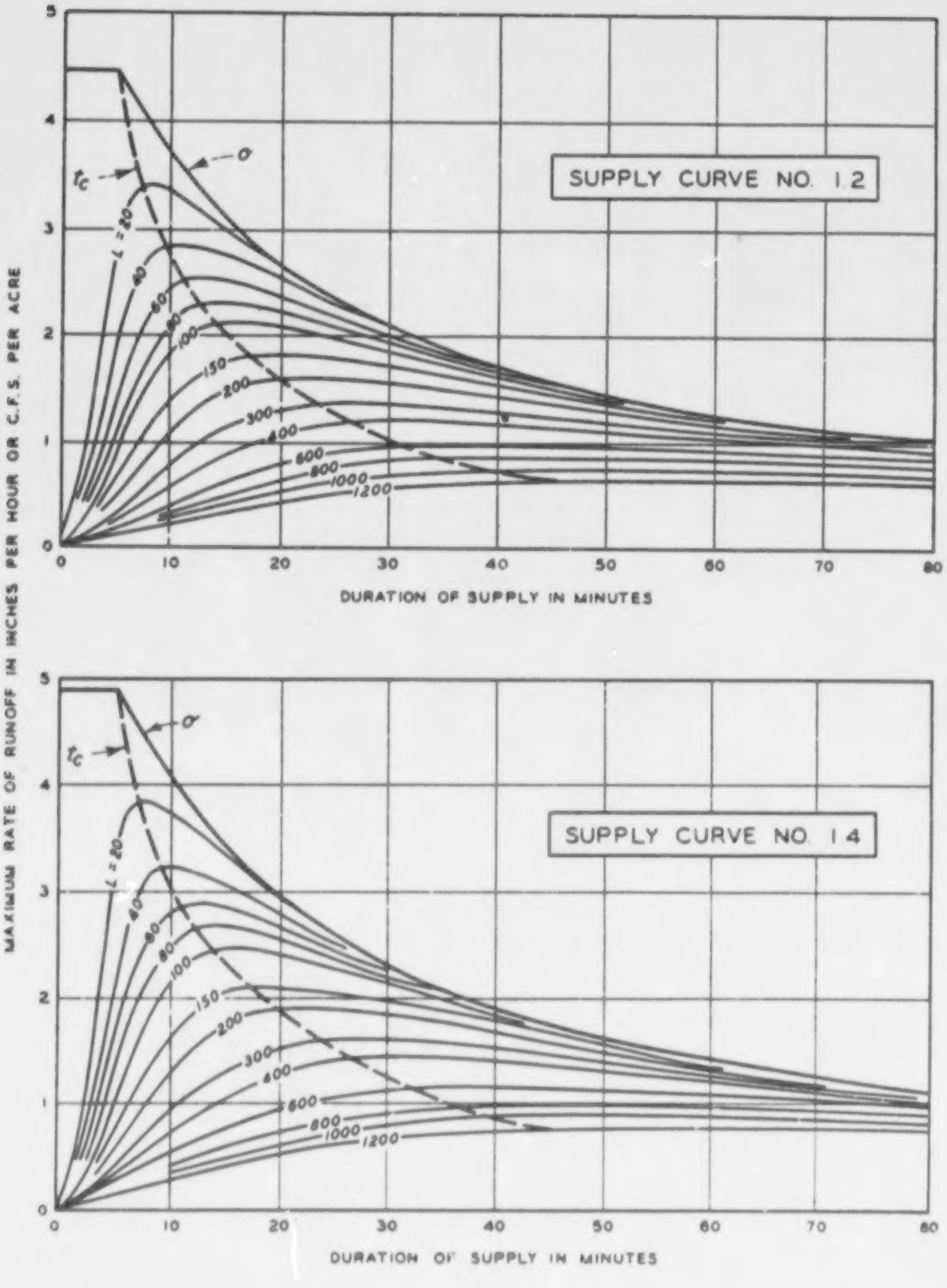


Figure 2A-6. Supply curves.

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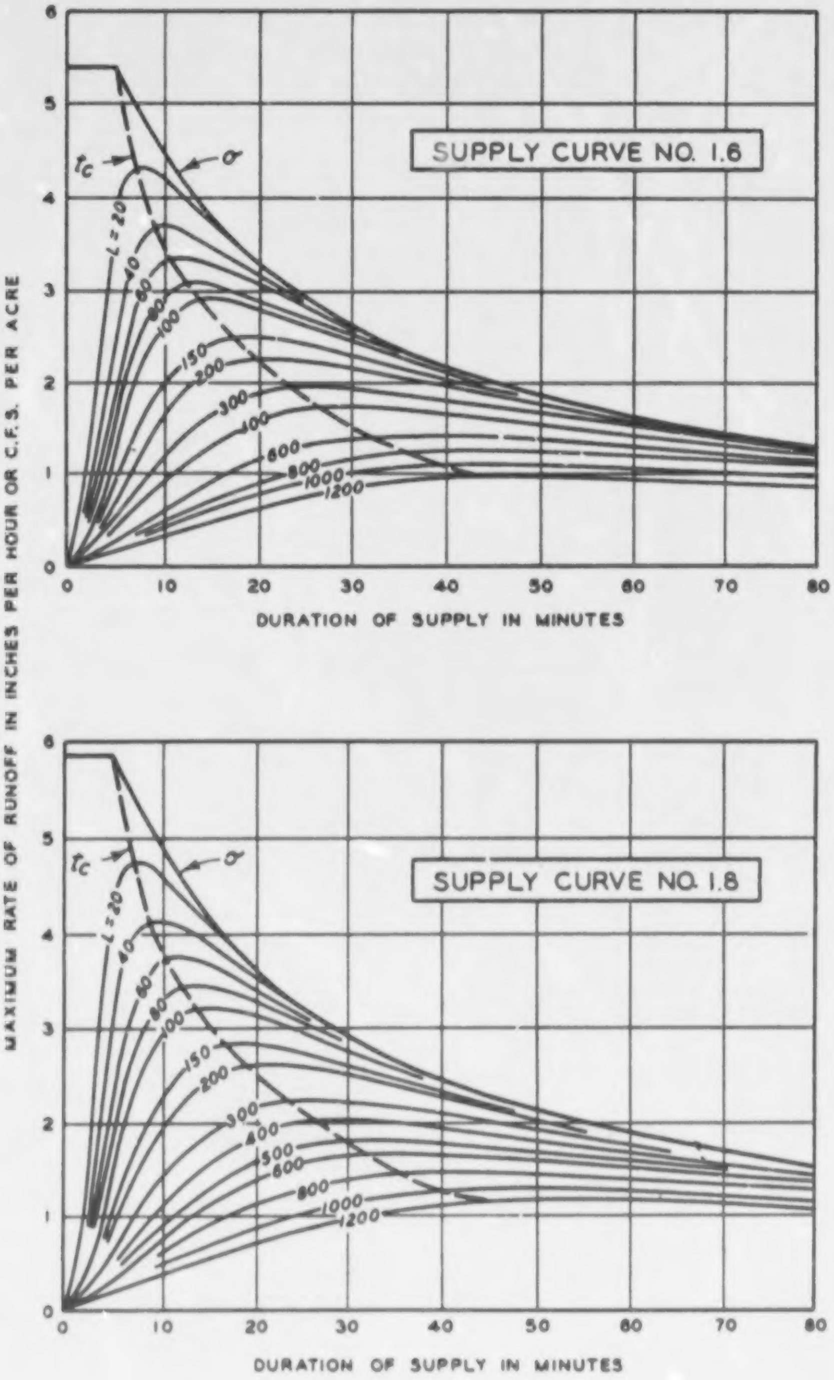

Figure 2A-7. Supply curves.

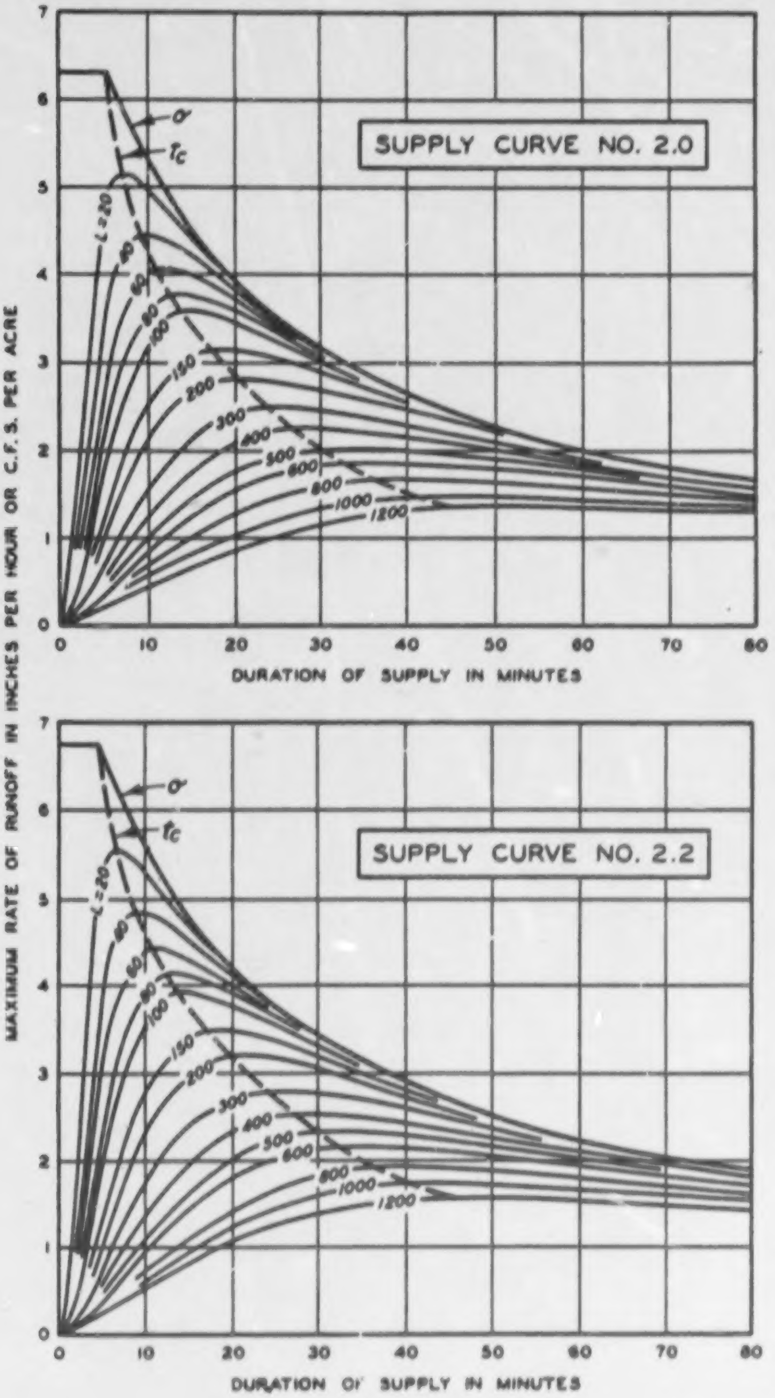

Figure 2A-8. Supply curves.

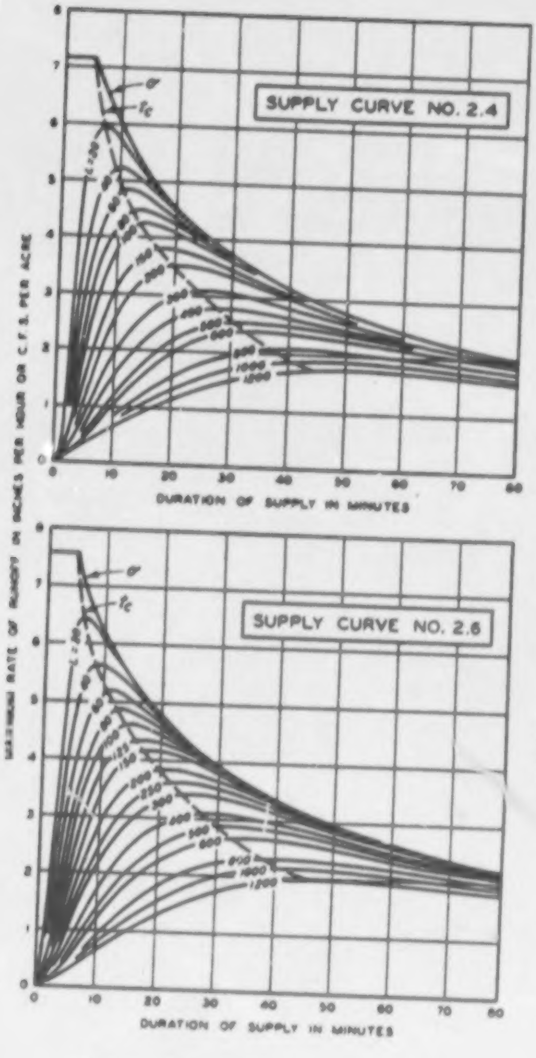

Figure 2A-9. Supply curves.

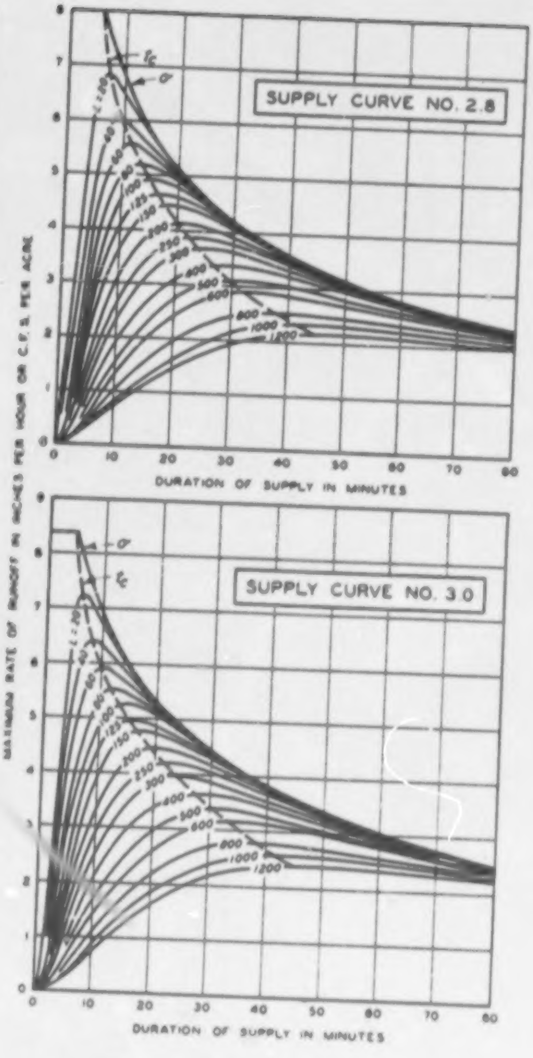

Figure 2A-10. Supply curves.

(b) Review the plans and specifications for type of man-made surfaces.

(2) Use engineering judgment and select an "n" for each type of flow.

i. Calculate the area equivalent length.

(1) For simple areas, determine the L_E for sheet, channelized, and ditch flow from figure 2A-2, using the coefficient of retardation, average length, and average slope for each type of flow. Add the equivalent lengths of all types of flow to get a total-area equivalent length.

(2) For complex areas, determine the L_E for sheet, channelized, and ditch flow respectively in each subarea from figure 2A-2, using the coefficient of retardation, average length, and average slope for sheet, channelized, and ditch flow in each subarea. Total the equivalent lengths for each subarea. Then calculate a weighted equivalent length for the total area by the equation,

$$\text{Weighted } L_E = \frac{A_1 L_{E_1} + A_2 L_{E_2} + \ldots.}{A_1 + A_2 + \ldots.}$$

(3) For successive areas it is necessary to add the equivalent length (total or weighted) of each successive area (simple or complex) to the equivalent length of channelized and/or ditch flow required to carry the runoff from each successive area to the drainage structure under consideration. Then a weighted equivalent length is computed by the same method used for a complex area,

$$\text{Weighted } L_E = \frac{A_1 L_{E1} + A_2 L_{E2} + \ldots}{A_1 + A_2 + \ldots}$$

(4) When the calculated equivalent length is longer than the 1,200 feet on the supply curves, use the 1,200-foot line.

j. Select a design storm rainfall (R) from the United States (fig 2A-3) or the world isohyetal maps (fig 2-5, lesson 2).

k. Select a rate of infiltration (I).

(1) Study soil and surfaces of areas and subareas.

(a) Conduct a soil survey and/or reconnaissance to identify soil.

(b) Review plans and specifications to determine if man-made surfaces are watertight.

(2) Refer to table 2A-2 (infiltration rates).

(3) Use engineering judgment and select "I's".

l. Calculate the area supply rate (σ).

(1) For simple areas the area supply rate is calculated from the equation, $\sigma = R - I$.

(2) For complex areas the area supply rate is the weighted supply rate calculated by the equation, $\sigma_1 = R - I_1$, $\sigma_2 = R - I_2$, etc.

$$\text{Weighted } \sigma = \frac{A_1 \sigma_1 + A_2 \sigma_2 + \ldots.}{A_1 + A_2 + \ldots.}$$

(3) For successive areas the weighted supply rate for all areas is calculated by the equation in para 2A-7l(2).

m. Choose the supply curve closest to the area supply rate.

n. Using the area equivalent length, determine the maximum rate of runoff per acre (Q/acre or Q/A) and the time of concentration (TOC) as indicated by the critical time of runoff (t_c) line on the chosen supply curve (figs 2A-4 through 2A-10).

o. Calculate the maximum rate of runoff (Q) in cubic feet per second (cfs) by multiplying the maximum rate of runoff per acre by the total area in acres (Q = Q/A × area in acres).

2A-8. SAMPLE PROBLEM FOR COMPUTING RUNOFF FOR SIMPLE AREA

a. Assume that you have been furnished with the following information:

Area #1: Fort Belvoir, Virginia. The drainage area has been delineated and flow paths have been located on the map.

Area map: See figure 2A-11 (Scale 1 in = 200 ft)

TABLE 2A-2. *Infiltration Rates (for 1 Hour) in Inches Per Hour*

Major Divisions		Letter		Dense Cover	Average Cover	Sparse (Bare) Cover
Coarse Grained	Gravel & Gravelly Soils	GW		1.0 - 1.3	0.8 - 1.2	0.6 - 1.0
		GP		1.0 - 1.3	0.8 - 1.2	0.6 - 1.0
		GM	d	0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
			u	0.4 - 0.5	0.3 - 0.4	0.2 - 0.3
		GC		0.3 - 0.4	0.2 - 0.3	0.1 - 0.2
	Sand & Sandy Soils	SW		1.0 - 1.5	0.8 - 1.2	0.6 - 1.0
		SP		1.0 - 1.5	0.8 - 1.2	0.6 - 1.0
		SM	d	0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
			u	0.4 - 0.5	0.3 - 0.4	0.2 - 0.3
		SC		0.3 - 0.4	0.2 - 0.3	0.1 - 0.2
Fine Grained	Silts & Clays WL 50	CL		0.1 - 0.2	0.1 - 0.2	0.02-- 0.1
		ML		0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
		OL		0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
	Silts & Clays WL 50	CH		0.1 - 0.2	0.1 - 0.2	0.02 - 0.1
		MH		0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
		OH		0.1 - 0.2	0.1 - 0.2	0. 02 - 0.1
Highly Organic	Soils	PT		0.6 - 0.8	0.4 - 0.6	0.2 - 0.4

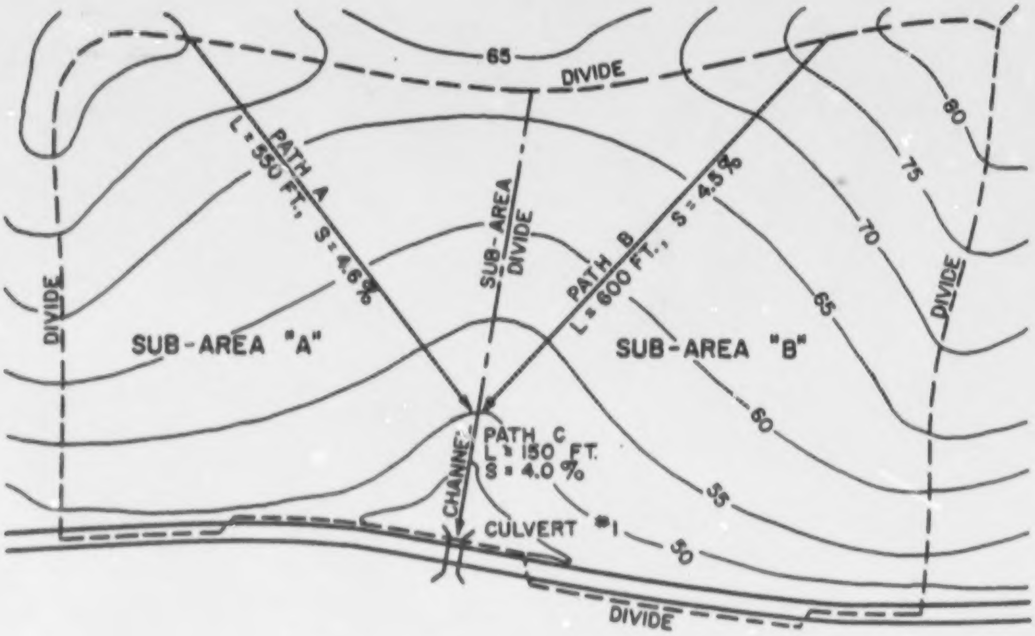
65
DIVIDE
PATH A
L = 550 FT., S = 4.6%
SUB-AREA DIVIDE
PATH B
L = 600 FT., S = 4.5%
80
75
70
65
60
55
50
DIVIDE
DIVIDE
SUB-AREA "A"
SUB-AREA "B"
PATH C
L = 150 FT.
S = 4.0 %
CHANNEL
CULVERT #1
DIVIDE

Figure 2A-11. Simple-area map (area #1).

Invert elevation of culvert #1 inlet: 44 ft

Average grass cover

Soil type: GMd

Turf area: 14.6 acres

Asphalt area: 0.1 acres

You have been instructed to calculate the maximum rate of runoff at culvert #1 that is being contributed by area #1. Channelized flow will be assumed to start near the 50-foot contour.

b. Determine if area is simple or complex (par 2-2g). The area covered by turf was given as 14.6 acres, and the area covered by asphalt was given as 0.1 acres. The total area is 14.7 acres.

$$\frac{14.6}{14.7} \times 100 = 99.3 \text{ percent}$$

Since one type area exceeds 80 percent of the total area, the drainage area is considered a "simple" area.

c. It is recommended that you use a table similar to table 2A-3 in computing runoff. This will aid you in organizing and recording your calculations.

d. Examination of the map, figure 2A-11, will reveal that subarea "A" is approximately equal in size to subarea "B". The ratio of each subarea to the total area is therefore about 1:2. From this analysis, it appears that one representative path of flow in each subarea should be sufficient to describe all paths of flow in each subarea. Water flows exactly perpendicular to the contour lines. However, for greater simplicity, flow lines are usually drawn as straight lines approximately perpendicular to the contours.

e. The following calculations illustrate how to complete table 2A-3.

(1) Scale paths A, B, and C.

(2) Compute the average slopes of all paths.

Example: Slope of path A $= \frac{75 - 50}{550} \times 100 = 4.6$ percent

(3) Compute L_E.

(a) Example: L_E for sheet flow (fig 2A-2).

Enter abscissa of figure 2A-2a at 575 and read up to "n" of 0.4. Read left to edge of graph and the result is 575. The reason there is no change in length is because "n" of 0.4 was used. Now enter the ordinate of figure 2A-2b at 575. Read across to slope of 4.6 percent. Read down to obtain corrected length for slope and the result is 275 ft. If the slope had been 1 percent, there would have been no correction for length.

(b) Example L_E for channelized flow (fig 2A-2).

Enter abscissa of figure 2A-2a at 150 and read up to "n" of 0.2. Read left to edge of graph and the corrected length for the difference in retardance coefficient is 75. Enter ordinate of figure 2A-2b at 75 and read across to slope of 4 percent. Read down to obtain the corrected length for the difference of slope, which is 40.

(c) Example L_E (by use of formula).

The formula $L_E = \frac{2.5\ Ln}{\sqrt{S}}$ can be used in lieu of figure 2A-2 to obtain the equivalent length for "n" of 0.4 and slope of 1 percent. This formula is recommended for the following reasons: (1) the scale of figure 2A-2 makes it difficult to select a number in the lower left-hand corner of each graph; (2) if you have an actual length greater than 600 feet, you must extend the line representing "n" or "S" by either inspection or calculation. The calculation for obtaining the equivalent length of flow is as follows:

$$L_E = \frac{2.5\ Ln}{\sqrt{S}} \qquad \text{where,}$$

L_E = equivalent length in feet for "n" of 0.4 and "S" of 1 percent.

L = actual or average measured distance of flow path in feet.

n = retardance coefficient (table 2-1, lesson 2).

S = actual or average slope, in percent, of flow path.

Examples:

L_g for sheet flow =

$$\frac{(2.5)\ (575)\ (0.4)}{\sqrt{4.6}} = 268 \text{ ft}$$

L_g for channelized flow =

$$\frac{(2.5)\ (150)\ (0.2)}{\sqrt{4.0}} = 38 \text{ ft}$$

(d) It should be noted that the formula gives more accurate values than those shown in table 2A-3. However, the total L_g obtained by either method varies very little and the supply curves (figs 2A-4 through 2A-10) allow for a fairly large error in L_g due to the scale of each supply graph. For the solution of any exercise involving the determination of runoff it is recommended that you use the formula and check your results by using figure 2A-2 when solving for L_g. All the exercises in this subcourse will be based on the formula method.

(4) "Q" computations.

(a) Supply rate (refer to paragraph 2A-7l(1)).

R - I = 1.5 - 0.5 = 1.0 inch per hour.

(b) Maximum rate of runoff in cfs per acre (fig 2A-5).

Locate intersection of L = 315 on the t_c curve. Read down to abscissa of 23. This is the time of concentration (TOC) in minutes and represents the time it will take for the entire drainage area to be simultaneously contributing water to culvert #1. Next, relocate L = 315 on the t_c curve and read left to the ordinate of 1.1. This represents the maximum rate of runoff per acre.

(c) Maximum rate of runoff through culvert #1 (refer to paragraph 2A-7o).

Q = 1.1 × 14.7 = 16.2 cfs

2A-9. SAMPLE PROBLEM FOR COMPUTING RUNOFF FOR COMPLEX AREA

a. Assume that you have been furnished with the following information:

Area #2: Fort Belvoir, Virginia. This area is located directly below area #1 used in paragraph 2A-8 of this lesson.

Area map: See figure 2A-12 (Scale 1 in = 200 ft).

Invert elevation of culvert #2 inlet: 24 ft.

Average grass cover.

Soil type: GMd.

Turf area: 6.6 acres.

Asphalt area: 4.7 acres.

You have been instructed to calculate the amount of runoff that only area #2 is contributing to culvert #2.

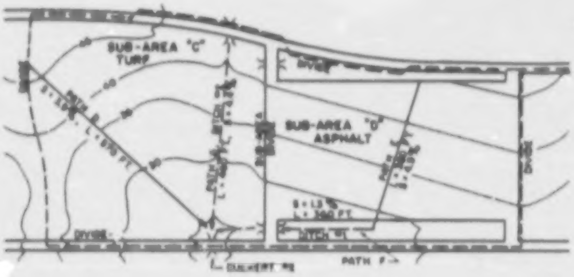

Figure 2A-12. Complex-area map (area #2).

TABLE 2A-3. *Simple-area "L_E" computations.*

AREA NO. 1 SURFACED 0.1 AC TURF 14.6 AC TOTAL 14.7 AC

TYPE FLOW	SHEET			CHANNELIZED					
n	0.4 (TABLE 2)			0.2 (TABLE 2)					
	PATH	L	S	PATH	L	S	PATH	L	S
	1A	550'	4.6%	1C	150'	4.0%			
	1B	600	4.5						
TOTAL		1150	9.1		150	4.0			
AVERAGE		575'	4.6%		150'	4.0%			
L_E	275' (FIG 3)			40' (FIG 3)					

TOTAL AREA L_E = 315'

"Q" COMPUTATION

AREA NO. 1 TOTAL AREA 14.7 AC R = 1.5 "/HR. (FIG 4) I = 0.5 "/HR. (TABLE III)

SUPPLY RATE = R - I = 1.5 - 0.5 = 1.0 "/HR.

CLOSEST SUPPLY CURVE = 1.0

Q/A = 1.1 CFS FOR L_E = 315 FT. (FIG 7)

TOC = 23 MIN. (FIG 7)

TOTAL Q = Q/A × AREA = 1.1 × 14.7 = 16.2 CFS

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b. Determine if area is simple or complex.

total area = 11.3 acres

$\frac{6.6}{11.3} \times 100 = 58.4$ percent

Since one type area does not exceed 80 percent of the total area, this drainage area is considered a "complex" area.

c. Examination of the map, figure 2A-12, will reveal that subarea "C" is approximately equal in size to subarea "D". The ratio of each subarea to the total area is therefore about 1:2. From this analysis, one representative path of flow in each subarea should be sufficient to describe all paths of flow in each subarea.

d. The following calculations illustrate how to complete table 2A-4.

(1) L_E for path D

$$L_E = \frac{2.5\ Ln}{\sqrt{S}}$$

$$= \frac{(2.5)\ (570)\ (.4)}{\sqrt{3.9}} = 288$$

(2) L_E for path E

$$L_E = \frac{2.5\ Ln}{\sqrt{S}}$$

$$= \frac{(2.5)\ (360)\ (0.02)}{\sqrt{4.5}} = 9$$

(3) L_E for path F

$$L_E = \frac{(2.5)\ (360)\ (.02)}{\sqrt{1.3}} = 16$$

(4) A × L_E for turf

(6.6) (288) = 1900

(5) I for turf = 0.5 (table 2A-2)

(6) σ for turf = R − I = 1.5 − 0.5 = 1.0

(7) A × σ for turf = 6.6 × 1.0 = 6.6

(8) Weighted $L_E = \frac{A_1 L_{E_1} + A_2 L_{E_2}}{A_1 + A_2}$ (Para 2A-71(2))

$$\text{Weighted } L_E = \frac{2018}{11.3} = 179 \text{ ft.}$$

(9) Weighted Supply Rate = σ = $\frac{A_1 \sigma_1 + A_2 \sigma_2}{A_1 + A_2}$ (para 2A-71(2))

Weighted Supply Rate = $\frac{13.7}{11.3}$ = 1.21 inches per hour

(10) For area #2 the maximum rate of runoff is 19 cfs at culvert #2.

2A-10. SAMPLE PROBLEM FOR COMPUTING RUNOFF FOR SUCCESSIVE AREAS

a. What is the maximum rate of runoff at culvert #2 from areas #1 and #2 shown in figures 2A-11 and 2A-12 respectively?

b. For this problem it is assumed that the runoff from area #1 (simple-area sample problem, para 2A-8) flows from culvert #1 through ditch #2 to culvert #2 and contributes to the runoff from area #2 (complex-area sample problem, para 2A-9) upon arriving at culvert #2.

c. To solve a successive-area problem, it is first necessary to determine the equivalent length of flow from each area contributing to the area outlet in question. Then the equivalent length of each contributing area and the supply rate of each contributing area are weighted with respect to the total area. Table 2A-5 shows the computations that are needed to solve this problem.

d. The following calculations illustrate how to complete table 2A-5.

(1) Area #1

(a) L_E of 315 ft (Refer to para 2A-8; table 2A-3; fig 2A-11).

(b) L_E of 460 ft ditch shown in figure 2A-12.

$$L_E = \frac{2.5\ Ln}{\sqrt{S}}$$

TABLE 2A-4. *Complex-Area "L_E" Computations*

AREA NO 2 SURFACED 4.7 AC TURF 6.6 AC TOTAL 11.3 AC

TYPE FLOW	SHEET (TURF)			SHEET (SURFACED)			DITCH		
n	0.4			0.02			0.02		
	PATH	L	S	PATH	L	S	PATH	L	S
	2D	570'	3.9%	2E	360'	4.5%	2F	360'	1.3%
TOTAL		570'	3.9		360	4.5		360	1.3
AVERAGE		570'	3.9%		360'	4.5%		360'	1.3%
L_E	288'			9'			16'		
TOTAL AREA L_E = 288'				TOTAL AREA L_E = 25'					

COMPLEX AREA R = 1.5 "/HR

AREA	ACRES	L	A × L_E	I	σ	A × σ
TURF	6.6	288'	1900	0.5	1.0	6.6
SURF	4.7	25'	118	0.0	1.5	7.1
TOTAL	11.3		2018			13.7

WEIGHTED $L_E = \frac{\text{TOTAL } A \times L_E}{\text{TOTAL } A} = \frac{2018}{11.3} = \underline{179}$ FT.

WTD. SUPPLY RATE $= \frac{\text{TOTAL } A \times \sigma}{\text{TOTAL } A} = \frac{137}{11.3} = \underline{1.21}$ "/HR.

CLOSEST SUPPLY CURVE 1.2

Q/A = 1.7 CFS FOR WTD. L_E = 179 FT.

TOC = 19 MIN.

TOTAL Q = Q/A × TOTAL AREA = 1.7 × 11.3 = 19.2 CFS

TABLE 2A-5. *Successive Area Computations*

AREA No 1

FOR SUCCESSIVE AREAS	TYPE FLOW	PATH	L	S	n	L_E
	AREA 1 L_E TO AREA OUTLET (CULVERT No 1)					315'
	DITCH (No 2)	2G	460'	4.4%	0.02	11'

TOTAL L_E AT ULTIMATE OUTLET = 326

AREA No 2

FOR SUCCESSIVE AREAS	TYPE FLOW	PATH	L	S	n	L_E
	AREA 2 L_E TO AREA OUTLET (CULVERT No 2)					179

TOTAL L_E AT ULTIMATE OUTLET = 179

SUCCESSIVE AREAS

R = ___ "/HR.

AREA	ACRES	L_E	$A \times L_E$	I	σ	$A \times \sigma$
1	14.7	326	4792	—	1.0	14.7
2	11.3	179	2023	—	1.2	13.6
TOTAL	26.0		6810			28.3

WEIGHTED $L_E = \frac{\text{TOTAL } A \times L_E}{\text{TOTAL } A} = \frac{6810}{26.0} = $ 262 FT.

WTD. SUPPLY RATE $= \frac{\text{TOTAL } A \times \sigma}{\text{TOTAL } A} = \frac{28.3}{26.0} = $ 1.09 "/HR.

CLOSEST SUPPLY CURVE 1.0

Q/A = 1.1 CFS FOR WTD. L_E = 262 FT.

TOC = 21 MIN.

TOTAL Q = Q/A × TOTAL AREA = 1.1 × 26.0 = 28.6 CFS

$$= \frac{(2.5)\ (460)\ (0.02)}{\sqrt{4.4}}$$

$$= \frac{23.0}{2.1} = 11.0 \text{ ft}$$

(2) Area #2

L_s of 179 ft (Refer to para 2A-9; table 2A-4; fig 2A-12).

(3) Successive areas

(a) Weighted $L_s \dfrac{A_1 L_{s_1} + A_2 L_{s_2}}{A_1 + A_2}$

(Paragraph 2A-71(3))

Weighted $L_s = \dfrac{6{,}810}{26.0} = 262$ ft

(b) Weighted supply rate $= \sigma =$

$$\frac{A_1 \sigma_1 + A_2 \sigma_2}{A_1 + A_2}$$

Weighted supply rate $= \dfrac{28.3}{26.0}$

$= 1.09$ inches per hour

(4) Maximum rate of runoff at culvert #2 from areas #1 and #2 = 28.6 cfs.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space below the question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in the back of this booklet. Do not send in your answers to these review exercises.

1. In Talbot's formula method how is the slope, cover, and shape of the drainage area accounted for? (2A-5)

2. In adjusting the value of "C" for Talbot's formula, which way is it adjusted as the length of the drainage area decreases in relation to its width? (2A-5)

3. Referring to table 2A-1, what size culvert opening would be required for a drainage area of 75 acres in flat terrain? (table 2A-1)

4. Using the nomograph on figure 2A-1, what diameter of round pipe, in inches, would be required to drain 100 acres of rolling terrain (use C = 0.4). (figure 2A-1)

5. Using the appropriate mathematical formula, what diameter pipe, in inches, would you order if you had determined the required waterway area to be 7 square feet? (2A-5)

6. Curves developed from Horton's equation for use in the Corps of Engineers method for determining runoff are based upon a specific retardance coefficient and surface slope. When these factors vary, how are the curves used? (2A-6e)

7. To use the curves referred to in exercise 6 when the area of concern is a complex area, what action must be taken with regard to the equivalent length? (2A-6e)

8. How do you determine the equivalent length of flow for a simple area in which sheet, channelized, and ditch flow are all present? (2A-7l(1))

9. Infiltration rates as given in table 2A-2 have a considerable range spread percentagewise. How is the specific figure selected? (2A-7k(3))

10. Of the supply curves shown in figures 2A-4 through 2A-10, how do you determine which one to use? (2A-7l, m)

LESSON 3

DESIGN OF DITCHES AND CULVERTS

CREDIT HOURS	2
TEXT ASSIGNMENT	Attached memorandum.
MATERIALS REQUIRED	Annex A.
LESSON OBJECTIVE	To teach you deliberate methods of ditch and culvert design.
SUGGESTIONS	Read the attached memorandum through rapidly to obtain a knowledge of its scope. Then read it through carefully, underlining the important points and objectives. Scan Annex A. Read the review questions at the end of the lesson. Study the lesson, searching for answers to the review questions, and write your answers in the spaces provided. Finally, check your answers with the answers given for this lesson at the back of this booklet. Review as necessary.

ATTACHED MEMORANDUM

3-1. GENERAL

In lesson 2 you learned how to compute surface runoff. This lesson will teach you how to design the ditches and culverts that must be used to carry this surface runoff from the drainage area.

3-2. MANNING'S FORMULA

a. After the discharge has been computed, the required channel or pipe sizes for various parts of the drainage system can be determined. All drainage structures must be large enough to carry away the maximum design discharge. To prevent infiltration into the subgrade, water should not stand in drainage facilities except for very brief periods. Where existing drainage structures are to be used, they must be checked to determine whether they will be adequate to carry any increased runoff resulting from the proposed construction. The size and gradient of pipes and well-maintained channels required to discharge design storm runoff may be determined by Manning's formula:

$$Q = A \frac{1.486}{n} R^{2/3} S^{1/2} \text{ where,}$$

Q = rate of flow in cfs

A = cross-sectional area of flow in sq ft

1.486 = a constant

n = a coefficient of roughness (Manning's "n")

S = slope in feet per foot

R = hydraulic radius in feet. (Area of flow divided by the wetted perimeter (wp).)

b. The wetted perimeter used to calculate the hydraulic radius is the lineal measurement of that portion of the perimeter of the ditch or structure actually wetted by the flow. The mathematical formulas for determining the values of wetted perimeters are as follows:

(1) V-ditches: (fig 3-1)

$$wp = 2\sqrt{\left(\frac{ad}{h}\right)^2 + d^2}$$

(2) Trapezoidal ditches: (fig 3-2)

$$wp = 2\sqrt{\left(\frac{ad}{h}\right)^2 + d^2} + b$$

(3) Culverts, full
$wp = \pi d$

c. Manning's coefficient of roughness (n) is based on the friction between the water and the ditch or culvert surface. In the field the value of n is determined from experience. Annex A-2 gives normal values of n for most surfaces. If time is a vital factor in ditch or culvert construction, an n = 0.025 may be assumed for hasty construction.

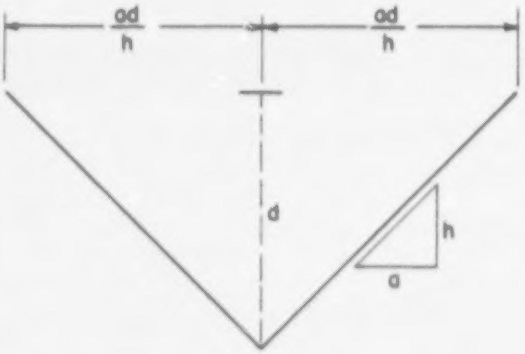


Figure 3-1. Cross section of a V-ditch.

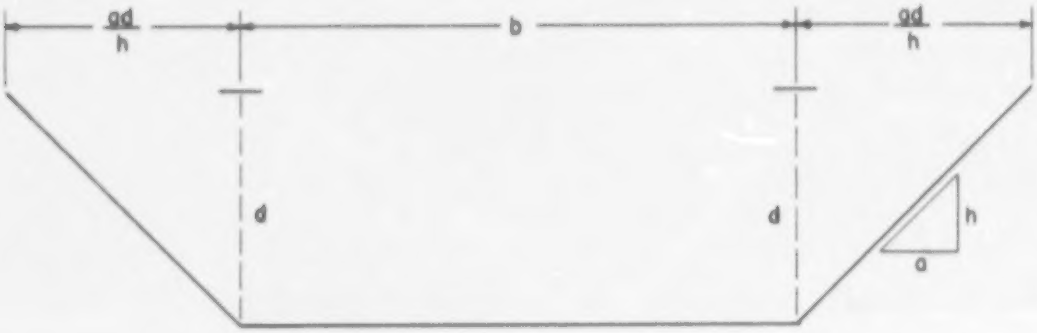


Figure 3-2. Cross section of a trapezoidal ditch.

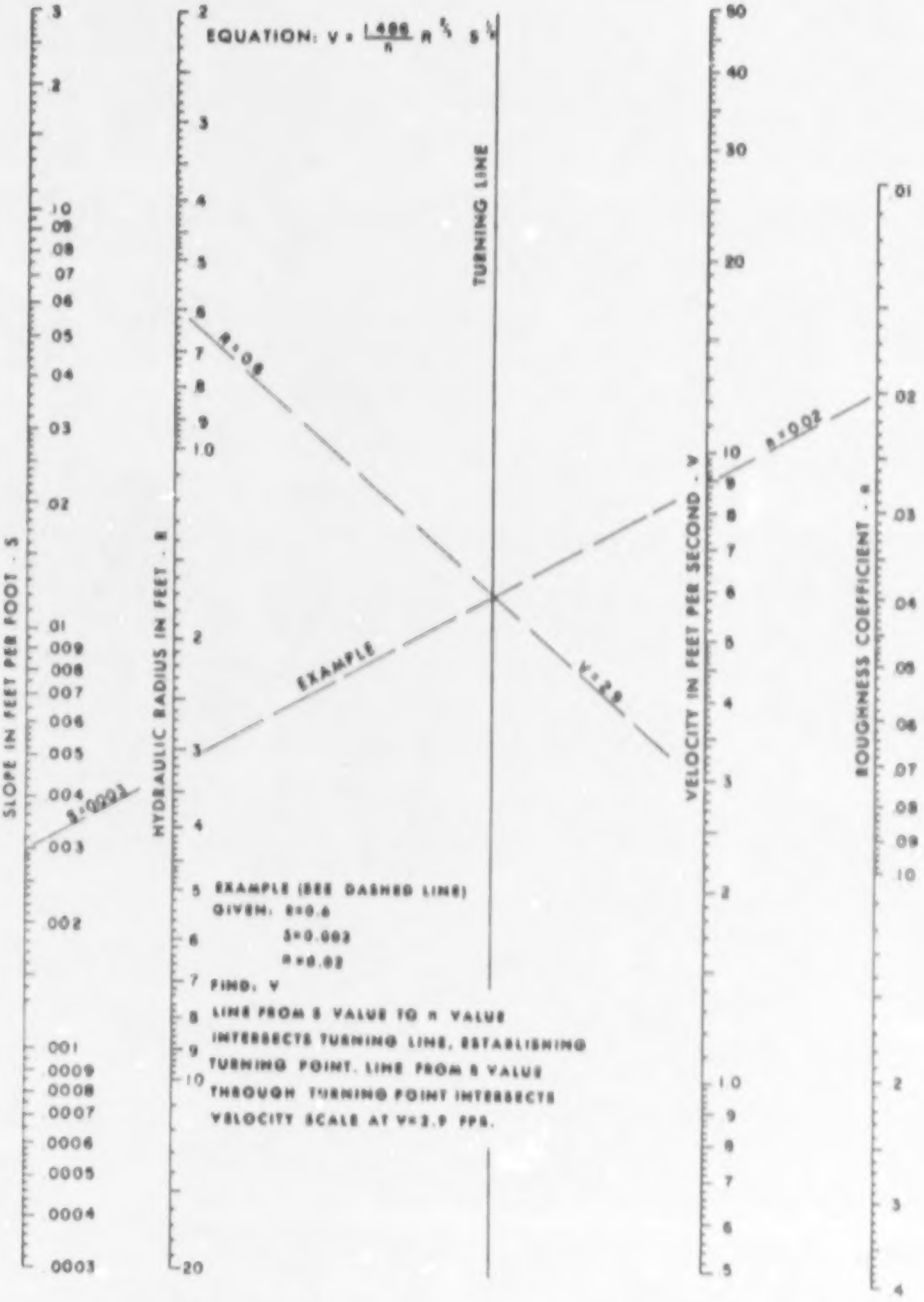
d. The slope in feet per foot (S) is either measured in the field or given in the design specifications.

e. The hydraulic radius is determined by dividing the cross-sectional area of flow by the wetted perimeter. For example a V ditch with 4 to 1 side slopes and a depth of 1 foot would have a hydraulic radius equal to:

$$R = \frac{\frac{8 \times 1}{2}}{2\sqrt{(4^2 + 1^2)}}$$

$$= \frac{4}{2\sqrt{17}} = 0.485 \text{ ft}$$

f. Figure 3-3 will be found useful in reducing some of the more laborious calcula-



EQUATION: $V = \frac{1.486}{n} R^{2/3} S^{1/2}$

EXAMPLE (SEE DASHED LINE)
GIVEN: R=0.6
S=0.003
n=0.02
FIND: V
LINE FROM S VALUE TO n VALUE INTERSECTS TURNING LINE, ESTABLISHING TURNING POINT. LINE FROM R VALUE THROUGH TURNING POINT INTERSECTS VELOCITY SCALE AT V=2.9 FPS.

Figure 3-3. Nomograph for Manning's formula.

tions involved in the solution of Manning's formula.

3-3. EXAMPLES

The following examples show the principles involved in determining the depth of flow of a ditch for a given longitudinal slope, roughness coefficient, and rate of runoff.

a. **V-ditch:** The area draining into the ditch has a rate of runoff (Q) of 10 cfs. The ditch has a 1 percent slope, a roughness coefficient (n) of 0.02 and side slopes of 4 to 1, as shown in figure 3-4.

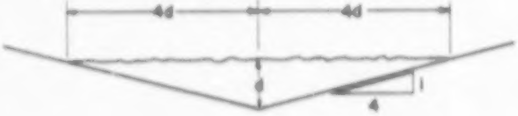


Figure 3-4. V-ditch used as example in paragraph 3-3.

Solution:

$$A = 4d^2$$

$$wp = 2\sqrt{16d^2 + d^2} = 8.25d$$

$$R = \frac{A}{wp} = \frac{4d^2}{8.25d} = 0.485d$$

Manning's formula $Q = A\,\frac{1.486}{n}\,R^{2/3}S^{1/2}$

$$10 = 4d^2\left(\frac{1.486}{0.02}\right)(0.485d)^{2/3}\ (0.01)^{1/2}$$

$$10 = 4d^2(74.3)\ (.485)^{2/3}(d)^{2/3}\ (0.01)^{1/2}$$

$$10 = 4d^{8/3}(74.3)\ (0.62)\ (0.1)$$

$$0.542 = d^{8/3}$$

$$d = 0.542^{3/8}$$

$$d = 0.795 \text{ or } 0.8 \text{ ft}$$

Knowing d we can now solve for the velocity (V) in the ditch by the formula $Q = VA$

$$V = \frac{Q}{A} = \frac{10}{4(.8)^2} = 3.9 \text{ ft/sec}$$

b. **Trapezoidal ditch.** The area drained by the trapezoidal ditch has a rate of runoff of 29 cfs. The ditch has a 0.6 percent slope, a roughness coefficient of 0.03 and the cross section of the ditch is shown in figure 3-5.

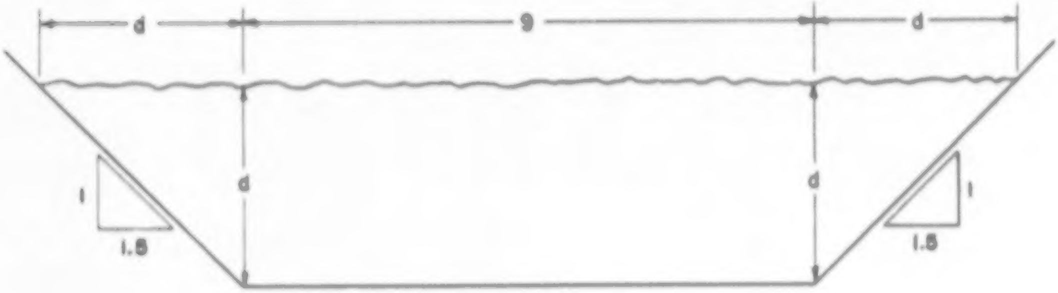


Figure 3-5. Trapezoidal-ditch section.

Solution:

$$A = 9d + 1.5d^2$$

$$wp = 2\sqrt{d^2 + (1.5d)^2} + 9$$

$$= 3.60d + 9$$

$$R = \frac{A}{wp} = \frac{9d + 1.5d^2}{3.60d + 9}$$

$$Q = A\,\frac{1.486}{n}\,R^{2/3}S^{1/2}$$

$$Q = (9d + 1.5d^2)\,\frac{1.486}{0.03}\left[\frac{9d + 1.5d^2}{3.60d + 9}\right]^{2/3}$$

$$Q = (9d + 1.5d^2)\left[\frac{9d + 1.5d^2}{3.60d + 9}\right]^{2/3}$$

$$(.0775)\ (49.53)$$

The solution of this equation by the usual means is lengthy and laborious involving several powers of d. It will be found simpler to solve by trial and error, using different values for d until you arrive at a value for Q approximately equal to 29.

Assume d = 1:

$$Q = 10.5\left(\frac{10.5}{12.6}\right)^{2/3}(3.84)$$

$$Q = 10.5(0.833)^{2/3}\ (3.84) = 10.5(0.885)\ (3.84)$$

$$Q = 35.7 \text{ cfs}$$

Since this is larger than the actual Q of 29 cfs, the assumed depth, 1 foot, is too large.

Assume d = 0.9:

$$Q = (8.1 + 1.22)\left[\frac{8.1 + 1.22}{3.24 + 9}\right]^{2/3}(3.84)$$

$$Q = 35.8\left(\frac{9.32}{12.24}\right)^{2/3}$$

$$= 35.8(0.760)^{2/3}$$

$$Q = 29.9 \text{ cfs}$$

Since the actual Q is 29 cfs it can be seen from the above calculation that the depth of flow to the nearest tenth of a foot is 0.9 ft.

Solving for the velocity in the ditch:

$$d = 0.9$$

$$A = 9d + 1.5d^2 = 8.1 + 1.22 = 9.32$$

$$V = \frac{Q}{A} = \frac{29.9}{9.32} = 3.2 \text{ ft/sec}$$

3-4. CONSTRUCTION EQUIPMENT CONSIDERATIONS

a. The shape of the cross-sectional area is primarily governed by the required ditch capacity and the capabilities of the available ditching equipment. For the development of ditch sizes, a steady and uniform flow, together with a constant longitudinal slope and roughness coefficient, are assumed; therefore the cross section of a given ditch will remain constant throughout its entire length. It is also normal practice to design ditches to have about 6 inches more depth than the depth of flow resulting from the design runoff (freeboard).

b. The most desirable combination of motorized construction equipment may rarely be available for ditch construction, but the same machines which are used in the grading operations are usable for ditch construction. The motorized grader is perhaps the best single machine for ditching, but other machines such as the towed scraper, motorized scraper, bulldozer, or crane-shovel with any excavation attachment may be used. The grader is primarily used in the construction of V-ditches but is also useful for constructing the side slopes of trapezoidal ditches. Graders can efficiently construct V-ditches up to a maximum depth of 2 feet with side slopes 4:1 or steeper. The scraper-grader combination is best for construction of trapezoidal ditches. The ditching limitation of this combination is a minimum ditch base width of 10 feet, the working width of the scraper. The ditch is usually dug to a minimum depth of 1 foot. Any side slope may be used that satisfies the hydraulic requirements of the flow in the ditch.

3-5. CULVERT DESIGN

A culvert is a conduit to convey water through an embankment. For such common and simple structures, culverts have never received the attention which they require. There is no substitute for the correct installation procedure as covered in lesson 4. In this lesson we are concerned principally with selecting the most economical size of culvert to carry the runoff through embankments. There are three factors which we must know about the culvert:

Type of pipe to be used: corrugated metal pipe (CMP); concrete pipe, etc.

Size of pipe to be used.

Slope of the culvert.

3-6. SIZE OF PIPE

After the slope and type of pipe have been selected, the size of the pipe can be determined. From the drainage analysis of the area we calculate the peak rate of runoff at the entrance to the culvert by Horton's formula. To select a pipe to handle this rate turn to annex A-4, table of pipe capacities. Annex A-4 is divided into two tables, one for corrugated metal pipe (CMP) and one for concrete pipe, because Manning's n is different for each type. For example, we have an area with a Q of 29.0 cfs, and several sizes of CMP on hand. What size CMP is needed to handle this runoff if the channel has a 1 percent slope? From annex A-4 we see that a 30-inch pipe will carry 22 cfs at 1 percent slope. Since this is less than the expected design runoff we will use a 36-inch pipe, which is capable of carrying 36 cfs when flowing full.

3-7. FACTORS AFFECTING FLOW

From annex A-4, you will notice that, up to a certain point, increasing the slope of a pipe increases the ability of that pipe to carry water. The point at which an increase in slope no longer increases the capacity is called the critical slope. For example a 36-inch CMP culvert reaches its maximum discharge at 1.6 percent slope. At this point the culvert is most efficient. When the slope exceeds the critical slope, the velocity of water increases but the depth becomes smaller so that the cross-sectional area is reduced. Because Q = VA, the same amount of water passes through the pipe as when it was at critical slope. Therefore, do not assume a steeper pipe will always increase your margin of safety. Instead, if the critical slope is exceeded, the velocity may be increased enough to cause severe erosion at the culvert outlet.

3-8. VELOCITY

Assume that a drainage system discharges a given volume of water. In most cases, when a water channel of this system is restricted in cross-sectional area the velocity of the water increases within the restricted portion. Since the culverts are more restricted in cross-sectional area than the ditches, it is very probable that the greatest velocities will occur in the culverts. Therefore an analysis of culvert velocities will usually indicate whether there are any excessive velocities in the drainage system. Annex A-4 shows the velocities for various sizes and slopes of pipe. If the velocity is above the acceptable limit, the ditch slope will have to be decreased, the ditch paved, or weir notch dams (lesson 4), installed to check erosion. Annex A-3 lists the maximum mean velocities for streams and channels. The minimum slope satisfactory for clear unlined channels is 0.5 percent.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space below the question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in back of this booklet. Do not send in your solutions to these review exercises.

1. What is the general criteria for determining the size of drainage structures? (3-2a)

2. What information will you obtain by proper application of Manning's formula? (3-2a)

3. Enter Manning's formula in the space below; it will be used frequently in the remainder of this lesson. (3-2a)

4. What is meant by the term "wetted perimeter?" (3-2b)

5. Write the formula for the wetted perimeter of a trapezoidal ditch. (3-2b(2))

6. What is the value of Manning's "n" for corrugated metal in good condition in an open channel, nonvegetated? (3-2c) (annex A-2, 7b)

7. How is the "hydraulic radius" of a drainage structure determined? (3-2e)

8. Determine the hydraulic radius of a V-ditch with 3 to 1 side slopes and a depth of 2 feet. (3-2e)

9. What is the hydraulic radius of a culvert 36″ in diameter when it is flowing full? (3-2b(3)) (3-2e)

10. What is the depth of flow (d) in a V-ditch if the runoff rate is 16 cfs, the ditch has a 1 percent slope, the roughness coefficient (n) is 0.02 and the side slopes are 3 to 1? (3-3a)

11. In the exercise above you were given a rate of flow of 16 cfs and you determined a depth of flow of 1 ft. You were also given a V-ditch with 3 to 1 side slopes. What is the velocity of flow? (3-3a)

12. Assuming you have solved Manning's formula to this point: $Q = (9d + 1.5d^2)\ (49.53) \left(\frac{9d + 1.5d^2}{3.6d + 9}\right)^{2/3} (.0775)$, and you have a runoff rate of 75 cfs, find the depth (d) by trial and error. (3-3b)

13. What are the two factors that primarily determine the shape of the cross-sectional area of a drainage ditch? (3-4a)

14. How much freeboard is normally allowed in the construction of a drainage ditch? (3-4a)

15. What is the minimum ditch base width that can be constructed using a combination of scraper and grader in construction of the ditch? (3-4b)

16. Name the three factors that must be known about a culvert to determine its carrying capacity. (3-5)

17. If you have a calculated runoff of 29 cfs and a 36-inch CMP available, what minimum slope should it be laid at? (3-6) (annex A-4)

18. What volume in cfs will a concrete pipe of 36-inch diameter carry if it is laid on a slope of 0.6 percent? (3-6) (annex A-4)

19. What is the critical slope upon which you may lay a 24-inch CMP? (3-7) (annex A-4)

20. At what slope does a culvert achieve its maximum efficiency? (3-7)

21. What will the velocity of water flow be in an 18-inch CMP if it is carrying 6.8 cfs? (3-8) (annex A-4)

22. What is the maximum allowable velocity for an erodible earth channel of ordinary firm loam if the water is clear except for fine silts? (3-8) (annex A-3)

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LESSON 4

DRAINAGE CONSTRUCTION, CHECK DAMS, DROP INLETS, CULVERTS, AND PONDING

CREDIT HOURS	3
TEXT ASSIGNMENT	Review lessons 1, 2, and 3. Attached memorandum.
MATERIALS REQUIRED	Annex A.
LESSON OBJECTIVE	To teach you how to install culverts, to design check dams, to design drop inlets, and to use ponding for safety and economy.
SUGGESTIONS	Read the attached memorandum through rapidly to obtain a knowledge of its scope. Then read it through carefully, underlining the important points and objectives. Read the review questions at the end of the lesson. Study the lesson, searching for answers to the review questions, and write your answers in the spaces provided. Finally, check your answers with the answers given for this lesson at the back of this booklet. Review as necessary.

ATTACHED MEMORANDUM

Section I. DRAINAGE CONSTRUCTION, CHECK DAMS, AND DROP INLETS

4-1. EXCAVATION OF DITCHES WITH EQUIPMENT

Open ditches with sloping sides may be excavated with a grader, dozer, scraper, power shovel, or dragline, depending on the size of the ditch and the prevailing working conditions. Narrow trenches or ditches with vertical sides normally are excavated with a ditcher if the soil is practically free of stone, boulders, or hard stratified material. This machine makes better progress if it travels downgrade while digging, but if water will accumulate in the trench during construction the trench must be excavated uphill to avoid working in water.

4-2. SIDE DITCHES

Water draining from the roadbed surface is collected into side ditches for disposal. These side ditches generally serve to collect water from a considerable area adjacent to the road. They should be of adequate size to accommodate the runoff both from the roadbed and from such adjacent areas. Side ditches are a potential danger to traffic. To reduce this danger to a minimum, the shoulders should be constructed as wide as practicable and with a slope toward the ditch. If possible, the required cross-sectional area should be obtained by constructing a broad shallow trapezoidal ditch. This type of ditch has a large capacity. Its minimum depth below the edge of the shoulder should be 1½ feet. The construction and maintenance of trapezoidal ditches with narrow bottom widths (less than grader or scraper width) is difficult, and may have to be done by hand. For flows up to 70 cfs, the V-ditch is probably more easily constructed and maintained. Side slopes should not be greater than 1½ to 1 in cohesive soil, and 3 to 1 in sandy or loamy soils. When possible, ditches should be deep enough to lower the ground-water table under the road to below the subgrade elevation, and thus permit drainage of the subgrade by seepage into the ditch. Where it is economically possible to develop and maintain turfed side slopes, the side slopes of ditches should not be steeper than 4 horizontal to 1 vertical, to facilitate mowing and operations incidental to maintenance. Ditches with comparatively flat side slopes must be protected against indiscriminate crossing of these ditches by vehicles. The longitudinal grade of the ditch must be great enough to provide free flow of water along the ditch, with velocities that are "self-cleaning" but do not cause erosion. To prevent the flow from standing in low places and seeping into the ground, a minimum grade of 0.5 percent should be maintained. The maximum grade depends upon the erosive tendencies of the soil in question. Soils with a high percentage of rock erode more slowly, for example, than clay or sandy soils. Where longitudinal grades of 4 percent or greater are encountered, high velocities, induced by large volumes of water, may require erosion control.

4-3. EROSION CONTROL

Erosion control is not only required to avoid possible hazards to moving traffic, but also to maintain an effective and clear drainage system with a minimum of maintenance. Erosion may occur at any point where the force of moving water exceeds the cohesive force of the material with which the water is in contact. There are numerous methods by which erosion control may be accomplished. Most methods of control are either based on dissipating the energy of water or on providing an erosion-resistant surface.

a. Terracing is a control measure designed to dissipate the energy of overland flow in nonuse areas. A terrace consists of a low, broad-based earth levee constructed approximately parallel to the contours, and designed to intercept and hold the water until it infiltrates into the soil or conduct it as overland flow to a suitable discharge point. Tables of vertical spacing and gradients of terraces are given in TM 5-330. Plans and the design of terraces are also adequately covered in this reference.

b. Turfing, check dams, placing riprap, and spreading rubble are control methods designed to cause turbulence and increase the retardance in order to dissipate the energy of flow in channels, ditches, and pipe outfalls. Ditches are often protected by placing strips of sod held in place by wooden boards or stakes perpendicular to the path of flow at intervals along a ditch.

c. Selection of the proper percent of slope for the type of materials contained in cuts and fills is a method of control based on design. Paving with asphalt or concrete may be used to provide an erosion-resistant surface in gutters, ditches, and pipe outfalls, and is usually required in ditches on grades in excess of 5 percent. Paving is not generally recommended because it is expensive and the water still has erosive energy which must be controlled at some point farther along the system.

4-4 CHECK DAMS

On sidehill cuts and steep grades, check dams are placed in side ditches to slow the water and prevent erosion. Check dams are not used when the grade exceeds 5 percent because this would require placing the dams too close together. In such cases, side ditches should be paved with boulders or timbers. Also, if erosion is a major problem, as in sand cuts, lined ditches are better than check dams.

a. Spacing. Check dams are spaced close enough to produce about a 40 or 50 to 1 slope. The drop for the check dam should be at least 1 foot and not more than 3 feet. Aprons to prevent scour on the downstream side of the check dam should extend approximately 3 feet for each foot of vertical drop between the bottom of the weir notch and the top of the apron. The formula for computing the space or distance between dams is as follows:

$$S = \frac{100 \times H}{A - B}, \text{ in which}$$

S = distance between check dams in feet

H = height of drop in feet for each check dam

A = original slope of water in ditch in percent

B = final slope of water in ditch in percent

To locate the dams on the ground divide the length of the ditch by the spacing. The first dam is always at the bottom of the adverse grade. For example, suppose you want to reduce the slope of an existing 550-foot ditch from 3 percent to 1 percent with check dams. The check dams are to have 1 foot of drop per dam. See figures 4-1 and 4-2 and table 4-1.

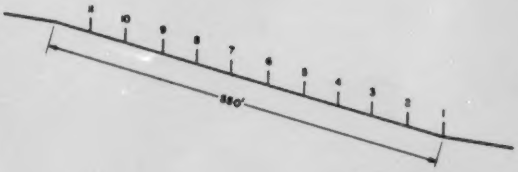


Figure 4-1. Check dam spacing.

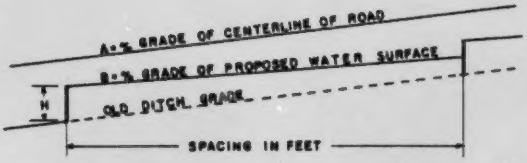

A=% GRADE OF CENTERLINE OF ROAD
B=% GRADE OF PROPOSED WATER SURFACE
OLD DITCH GRADE
H
SPACING IN FEET

Figure 4-2. Method of computing check dam spacing.

$$S = \frac{100 \times 1}{3 - 1} = \frac{100}{2} = 50 \text{ ft}$$

Number of dams required =

$$\frac{550}{50} = 11$$

The 11 dams will take up 11 feet of the difference in elevation of the ditch. 550 × .03 = 16.5 feet total drop in the ditch.

$$16.5 - 11 = 5.5 \text{ feet}$$

$$\frac{5.5}{550} \times 100 = 1 \text{ percent final slope of ditch}$$

TABLE 4-1. *Spacing of Check Dams*

Difference in slope (A – B) in percent.	Values of H, in feet				
	1	1½	2	2½	3
½	200	300	400	500	600
1	100	150	200	250	300
1½	67	100	133	167	200
2	50	75	100	125	150
2½	40	60	80	100	120
3	33	50	67	83	100
3½	29	43	57	71	86
4	25	38	50	63	75
4½	—	33	44	56	67

b. Weir notch. The weir notch is the discharge slot at the top of the check dam. The depth of flow may be assumed and the length of the slot then calculated by the formula $Q = CLH^{3/2}$, or the length of slot may be assumed and the depth of flow then calculated by the same formula. The slot is always constructed ½ foot deeper than the depth of flow as a safety factor (fig 4-3).

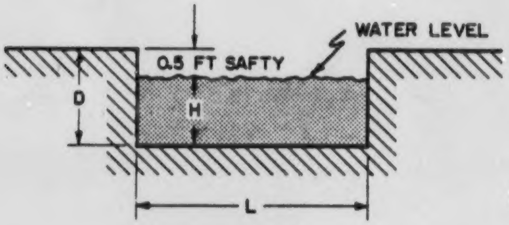


Figure 4-3. Weir notch.

$Q = CLH^{3/2}$

Q = peak rate of runoff through ditch in cfs

C = 3 (a constant)

L = length of weir notch in feet

H = depth of flow through notch in feet

Example of weir flow

$Q = CLH^{3/2}$

Given:

$Q = 5$ cfs

$C = 3$

$L = 2$ ft

Therefore:

$5 = 3\ (2)\ (H^{3/2})$

$$H^{3/2} = \frac{5}{6} = 0.833$$

$H = 0.885$

Add .5 feet for a safety factor

$D = 0.885 + 0.5 = 1.385$ feet

c. Construction. Check dams may be constructed of timber, sandbags, concrete, rock, or similar materials. They must extend at least 24 inches into the sides and bottom of the ditch. The height of top of ditch above top of check dam should be at least 12 inches. Side slopes of the ditch above and immediately below check dams will require protection from erosion. An apron must be provided to prevent scouring. The weir notch must have a large enough capacity to discharge the anticipated runoff, or water will back up and start cutting around the edges of the check dam. Typical check dam construction is illustrated in figure 4-4.

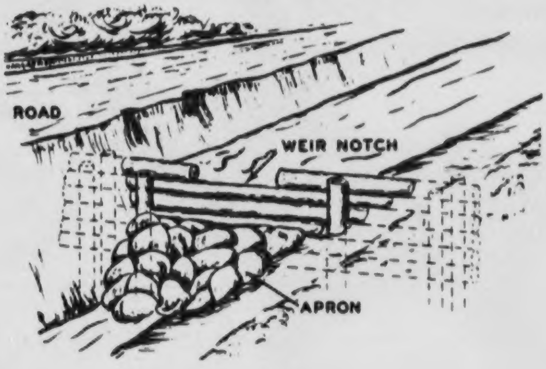


Figure 4-4. Check dam construction.

4-5. DROP INLETS

Situations calling for the use of drop inlets may arise when the runoff from a surfaced area, such as an apron for aircraft or a storage area, is too large to continue without interception before it leaves the area. Usually the area is graded so that the water is directed toward a shallow ditch where it is intercepted by grate heads (fig 4-5) which allow it to drop into underground pipes. The capacity of the grate depends upon the depth of water over the grate (head). Depending on the head, the orifice formula or the weir formula is used to determine the discharge of the grate (see table 4-2). A safety factor of 2.0 should be used for turfed areas where grass cuttings or other debris may collect in the grating. For paved areas, a safety factor of 1.5 should be used.

TABLE 4-2. *Discharge Capacities of Square Grate Inlets in Cubic Feet per Second*

Grate Size, Inches	Grate Opening, Sq.Ft.	Head of Water on Grate, Feet																	
		0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
6×6	0.12	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.2	1.3	1.5	1.6	1.8	1.9	2.0	2.1
9×9	0.28	0.7	1.0	1.2	1.4	1.5	1.7	1.8	1.9	2.0	2.1	2.6	3.0	3.4	3.7	4.0	4.3	4.5	4.8
12×12	0.50	1.1	1.7	2.1	2.4	2.7	2.9	3.2	3.4	3.6	3.8	4.7	5.4	6.0	6.6	7.1	7.6	8.1	8.5
15×15	0.78	1.3	2.7	3.2	3.8	4.2	4.6	5.0	5.3	5.6	5.9	7.3	8.4	9.4	10.3	11.1	11.9	12.6	13.3
18×18	1.12	1.6	3.8	4.7	5.4	6.0	6.6	7.1	7.6	8.1	8.5	10.5	12.1	13.5	14.8	16.0	17.1	18.1	19.1
21×21	1.53	1.9	5.2	6.4	7.4	8.2	9.0	9.7	10.4	11.0	11.6	14.2	16.4	18.4	20.1	21.8	23.3	24.7	26.0
24×24	2.00	2.2	6.1	8.3	9.6	10.7	11.8	12.7	13.6	14.4	15.2	18.6	21.5	24.0	26.3	28.4	30.4	32.2	34.0
30×30	3.12	2.7	7.6	13.0	15.0	16.8	18.4	19.9	21.2	22.5	23.7	29.1	33.6	37.5	41.1	44.4	47.5	50.3	53.1
36×36	4.50	3.2	9.1	16.7	21.6	24.7	26.5	28.6	30.6	32.4	34.2	41.9	48.3	54.0	59.2	63.9	68.3	72.5	76.4
42×42	6.12	3.8	10.6	19.5	29.4	32.9	36.0	38.9	41.6	44.1	46.5	57.0	65.9	73.4	80.9	87.0	93.0	98.7	104.0
48×48	8.00	4.3	12.1	22.3	34.3	43.0	47.1	50.8	54.3	57.6	60.8	74.4	85.9	96.0	105.2	113.7	121.5	128.9	135.9

NOTES:

1. Values to left of HEAVY line were calculated from the weir formula: $Q = 3LH^{3/2}$, L = Perimeter
2. Values to right of HEAVY line were calculated from the orifice formula: $Q = 5.37AH^{1/2}$, A = Grate Opening
3. Clear opening between grate bars was taken to be 50% of total grate area.
4. Estimated runoff should be increased 50% in paved areas.
5. Estimated runoff should be increased 100% in turfed areas.

Example:

Given: Q = 9.0 cfs
Head = 1.2 ft

What size grate would you use if the drainage area is turfed?

Solution: Since the drainage area is turfed, a safety factor of 2 should be used. The grate should be capable of discharging 2 × 9.0 or 18 cfs. From Table 4-2, a 30- by 30-inch grate (Q = 18.4 cfs) with a grate opening of 3.12 sq ft would be satisfactory. If the area were paved, a safety factor of 1.5 would be used. This would require a grate with a discharge of 1.5 × 9.0 or 13.5 cfs. A 30- by 30-inch grate would still be required since the next smaller size does not have sufficient capacity.

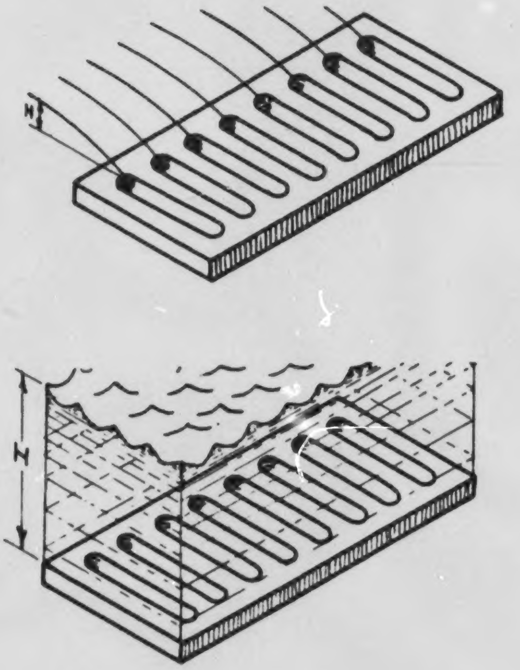


Figure 4-5. Grate heads.

4-6. CULVERT PLACEMENT

Culvert placement includes alinement, elevation, slope, spacing, foundation, backfill, and cover.

a. Alinement. Culverts are placed in natural drainage channels (fig 4-6) unless such installations would require an unusually long culvert or produce a sharp bend in the channel on the upstream side. Alinement is generally not changed where the angle between the stream and the embankment is 45° or more. If a meandering stream is encountered, the culvert should be installed at the best possible location and the stream channel straightened as necessary (fig 4-6). Where old drainage channels are not encountered, culverts should be installed perpendicular to the centerline of the traveled way. In sidehill cuts on steep grades, ditch-relief culverts should be installed at an angle of 60° to the centerline, to allow a more direct entrance of water into the culvert (fig 4-7).

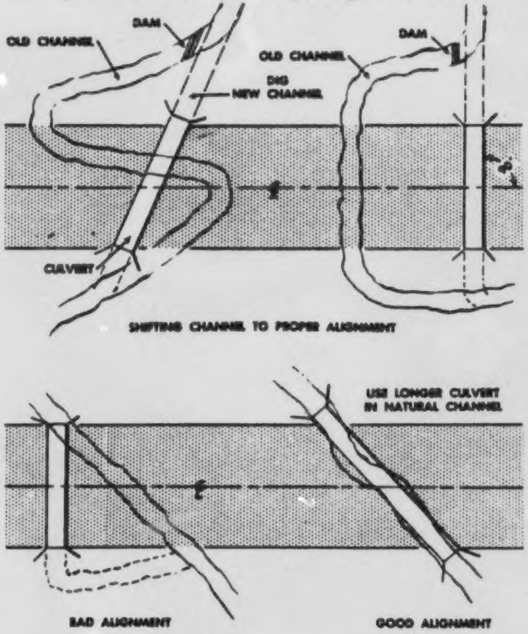


Figure 4-6. Alinement of culvert.

b. Elevation. At the inlet the bottom of the culvert is placed on or below, but not usually above, the streambed. It is possible to put the culvert above streambed elevation if the culvert must carry high flows and a small amount of ponding is permissible. If this is done, care must be taken to prevent

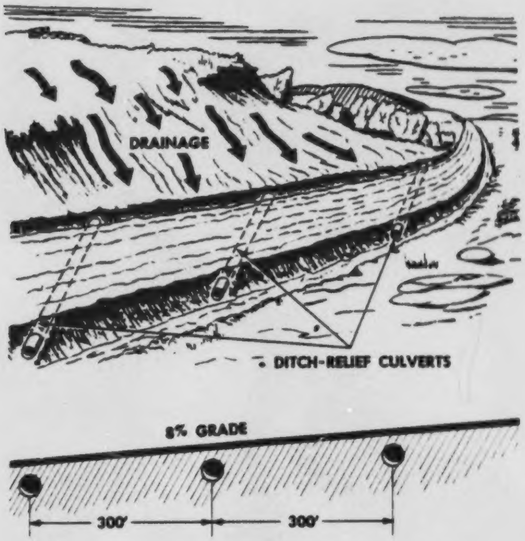


Figure 4-7. Spacing a ditch-relief culvert.

embankment saturation or seepage along the side of the culvert. Filling under a culvert to bring it to grade should be avoided. If necessary, place the inlet of the culvert below the natural streambed and use drop inlets or headwalls. Drop inlets require periodic removal of accumulated sediment. At the outlet end, the bottom of the culvert should normally be at the elevation of the surface of the stream since it may fill with sediment if placed below the surface. On sidehill cuts it may be necessary to place the lower end of the culvert above the stream. In this case, spillways are constructed to prevent erosion and backwash, or the culvert is extended beyond the fill (fig 4-8)

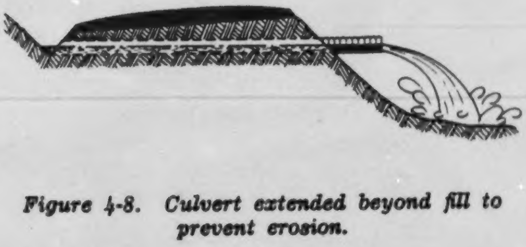


Figure 4-8. Culvert extended beyond fill to prevent erosion.

c. **Slope.** Normally, culverts are placed on the same slope as the natural and artificial drainage channels which discharge into them. It is generally desirable to use slopes from 2 to 4 percent. However, in extreme cases, where the fall of the land requires it, 0.5 percent slope may be used as the absolute minimum. Velocities, which may be determined by Manning's formula, should not be greater than 8 feet per second to avoid scouring, and not less than 2.5 feet per second to avoid sedimentation. Changes in the slope of the culvert should be avoided, but when changes are unavoidable, the culvert should be designed so that the steepest slope is at the outlet end. Where the outlet is below the ground surface in flat terrain, water should be dispersed in a progressively wider outlet ditch until the natural ground elevation is reached. In digging culvert ditches or installing culverts to slope, a reference string can be used. On a continuation of the culvert centerline, long stakes are driven about 1 foot outside the inlet and outlet ends of the culvert. These stakes are marked at a given distance above the inlet and outlet ends of the culvert and a string is stretched between these marks (fig 4-9).

d. **Spacing.** Culverts should be located wherever natural drainage channels are large enough to require cross drainage. On sidehill roads or wherever roads intercept surface water, either in cut or in fill, the water is drained to the low side of the road, and, if possible, away from the road by ditch-relief culverts (fig 4-7). On 8-percent grades, ditch-relief culverts should be placed about 300 feet apart; on 5-percent grades, 500 feet apart. The distance between pipes in multiple-pipe culverts should be at least one-half the diameter of the pipe (fig 4-10).

e. **Foundation.** Culverts are constructed on a firm, well-compacted soil foundation, except that box or arch culverts may be placed on rock foundation when suitable rock is encountered. The foundation is always shaped to fit, or bed, one-fourth of the outside circumference of the pipe (fig 4-10). In addition, foundations for pipe culverts are generally cambered, or convexed upward

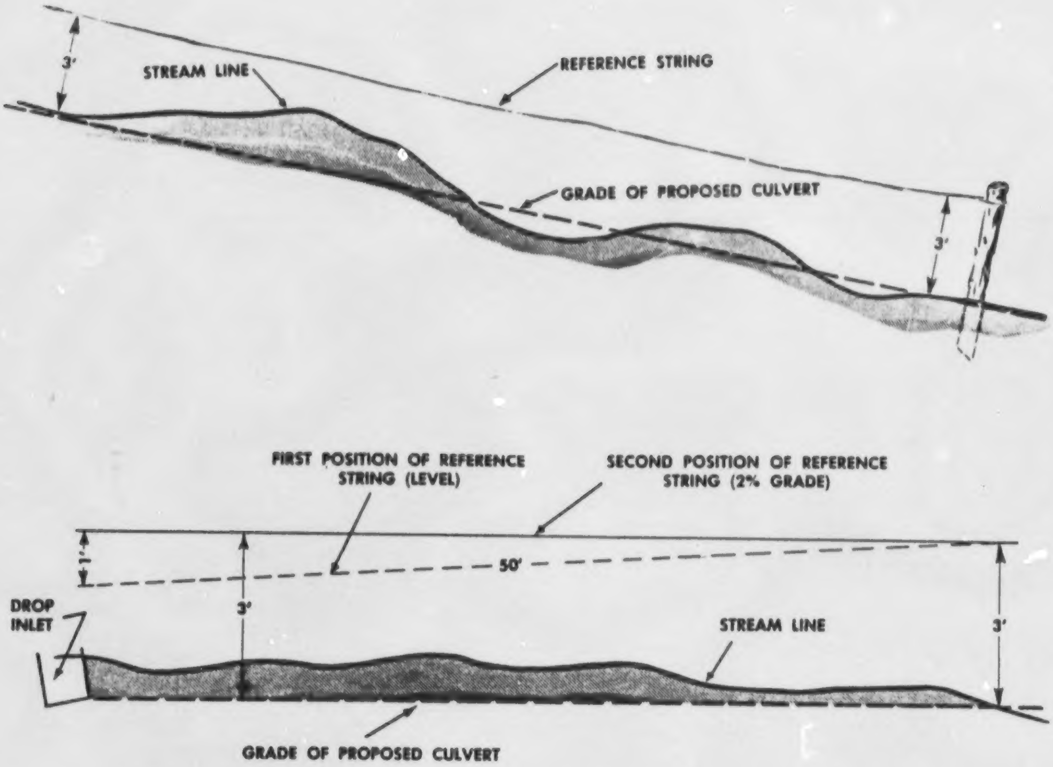

3'
STREAM LINE
REFERENCE STRING
GRADE OF PROPOSED CULVERT
3'
FIRST POSITION OF REFERENCE STRING (LEVEL)
SECOND POSITION OF REFERENCE STRING (2% GRADE)
1'
50'
DROP INLET
3'
STREAM LINE
3'
GRADE OF PROPOSED CULVERT

Figure 4-9. Establishing grade of culvert with reference string.

along the culvert centerline to correct for expected settlement and to insure tightness in the lower half of the joints. Sometimes cradles are built (for rigid pipe only) to provide proper support and to avoid uneven settlement. Cradles should never be used with flexible pipe because the soil below and at the side of the pipe should support the load uniformly. A cradle would create point supports leading to excessive deflection of the pipe and subsequent failure. The majority of flexible pipe failures are the result of inadequate compaction procedures. If the foundation is adequately compacted, a slight deflection of the flexible pipe will increase the supporting power of the surrounding soil. If, however, the foundation material around the culvert contains voids or is otherwise not properly compacted, a slight deflection of the flexible pipe will not result in a sufficiently increased supporting pressure from the foundation. Hence, the pipe must deflect still further to gain some support since the foundation material is the primary source of strength or support for a flexible pipe. This resultant increase in deflection will ultimately result in failure. If the bearing strength of the soil is completely inadequate, footings are placed to distribute the load. The spread footing can be adapted to various types of soil and all types of culverts except flexible culverts.

f. **Backfill.** Dirt is backfilled and tamped by hand or with a mechanical tamper to one-half the culvert depth, or to a depth sufficient to hold the culvert in place. The backfill is then completed with bulldozers and other equipment, but tamping is done by

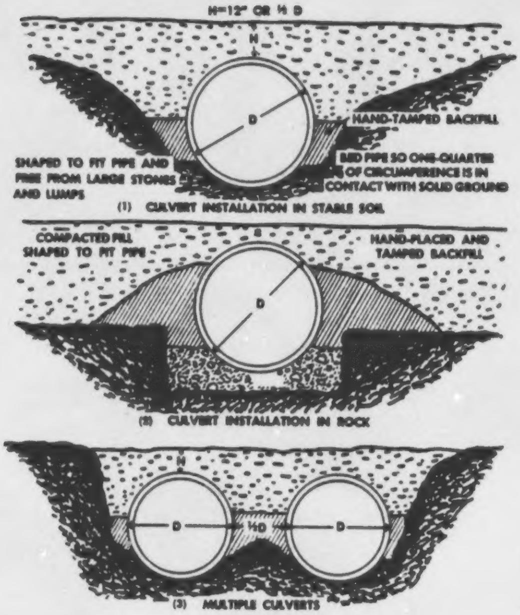

H=12" OR ½ D
H
D
HAND-TAMPED BACKFILL
SHAPED TO FIT PIPE AND FREE FROM LARGE STONES AND LUMPS
BED PIPE SO ONE-QUARTER OF CIRCUMFERENCE IS IN CONTACT WITH SOLID GROUND
(1) CULVERT INSTALLATION IN STABLE SOIL
COMPACTED FILL SHAPED TO FIT PIPE
HAND-PLACED AND TAMPED BACKFILL
D
(2) CULVERT INSTALLATION IN ROCK
H
D
½D
D
(3) MULTIPLE CULVERTS

Figure 4-10. Bedding culverts during installations.

hand or with a mechanical tamper to at least 12 inches above the culvert.

g. Cover. Culverts other than pipe should have a minimum of 12 inches (preferably 18 inches) of cover. Corrugated metal pipe (CMP) culverts, used in roads, should have a minimum cover of 18 inches or one-half the diameter of the pipe, whichever is larger. Cover for airfield culverts should be based on annex A-5. Cover is measured vertically from the outside edge of the shoulder to the top of the culvert.

4-7. LENGTH AND STRENGTH OF CULVERTS

Two principal considerations in culvert design are:

a. Length. The length of a culvert is determined by the width of the embankment at the location where the culvert is to be installed. Culverts must be long enough to prevent earth from being worked into them from the fill and also to prevent the roadbed or embankment from being scoured by the water as it leaves the culvert (figs 4-8 and 4-11). Usually, culverts should be long enough to extend completely through fills to the point where the fill slope meets the ground or streambed level. In some instances, such as on steep grades, excessive lengths can be avoided by placing the outlet above the toe of fill or above the stream level. For a cut section, the normal length would be equal to the distance from the bottom of the ditch on the upstream side to the bottom of the ditch on the outlet side. To minimize scour at the downstream end, culverts should be 1 or 2 feet longer than otherwise required, with the added length on the discharge end. In some instances it will be necessary to prevent scouring by constructing a toe ditch to carry the water off the slope. Avoid the use of pipes smaller than 12 inches in diameter for lengths up to 30 feet, or smaller than 15 inches for lengths over 30 feet. Small pipes

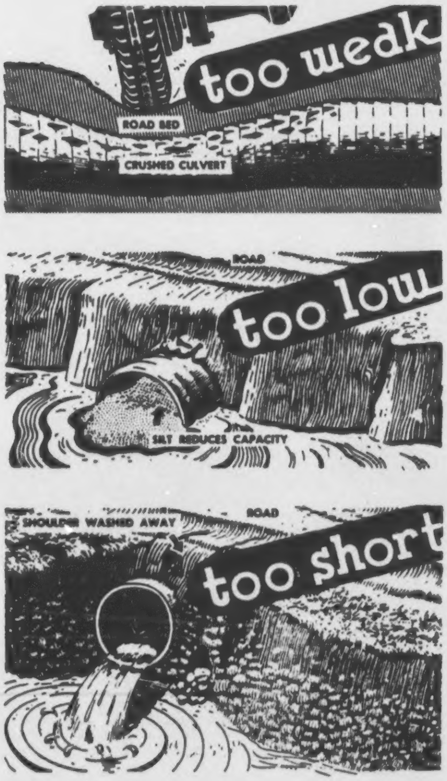

too weak
ROAD BED
CRUSHED CULVERT
ROAD
too low
SILT REDUCES CAPACITY
ROAD
SHOULDER WASHED AWAY
too short

Figure 4-11. Common causes of culvert failure.

clog easily and are difficult to maintain. If large headwalls are used, the length of the culvert may be shortened, but it usually takes less time, labor, and materials to build longer culverts without headwalls.

b. **Strength.** The culvert must be strong enough to carry the weight of the fill above it plus the weight of live loads that pass over the road, as illustrated in figure 4-11. Culverts are constructed to act as a single complete unit under loads. Annex A-6 gives recommended gages for nestable corrugated metal pipe under various heights of fill.

4-8. STRUTTING NESTABLE CORRUGATED METAL PIPE (CMP)

Nestable culvert pipe should be strutted after assembly and before backfilling. Strutting is used to give the pipe an oval shape with the long axis of the oval in the vertical plane before it is backfilled. After backfilling has been completed, the strutting is removed. As the backfill is further compacted by the pressure of the pipe and loads on the pipe, the pipe again becomes circular in shape.

a. **Size and placement of struts and sills.** The strutting members consist of one lower sill, two upper sills, vertical struts and, usually, compression caps. Jack struts and bearing blocks are used in placing the strutting members (fig 4-12). All members must be sound lumber. Struts and sills must be cut squarely in order to set level and join evenly. Compression caps must be about 10 inches long, to provide ample bearing on the two upper sills. Length of the vertical strut must be the elongated diameter of the pipe minus the combined thickness of the compression caps and the upper and lower sills. Jack struts are shorter than vertical struts, but long enough to accomplish the required stretching within the lifting range of the jack. All joints in upper and lower sills must be made at the vertical struts. However, the two upper sill members should not be jointed on the same vertical strut, but staggered on alternating struts (fig 4-13).

b. **Spacing of struts.** Spacing of struts in various sizes of pipe under different depths of fill is shown in table 4-3. The tools required include two 15-ton jacks, a crosscut saw, a hatchet, a carpenter's level, and a maul.

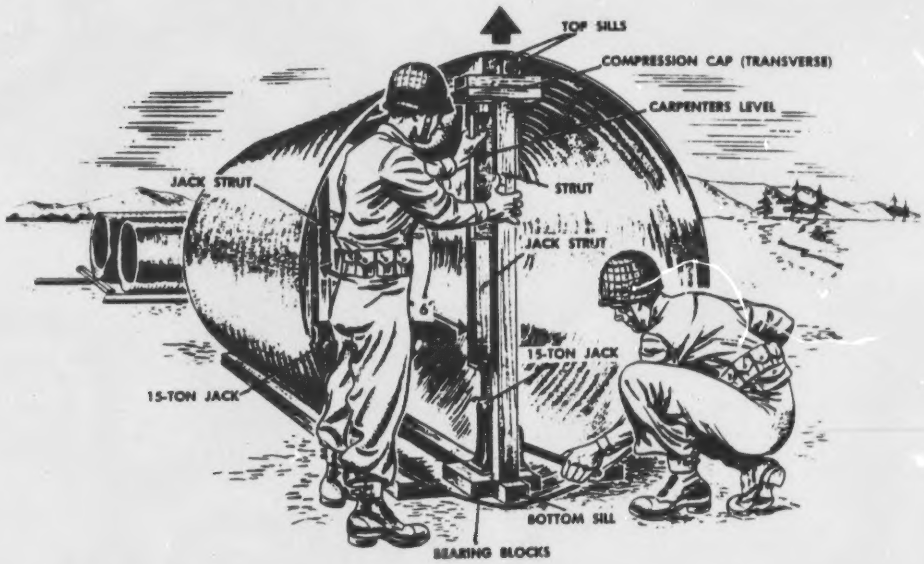
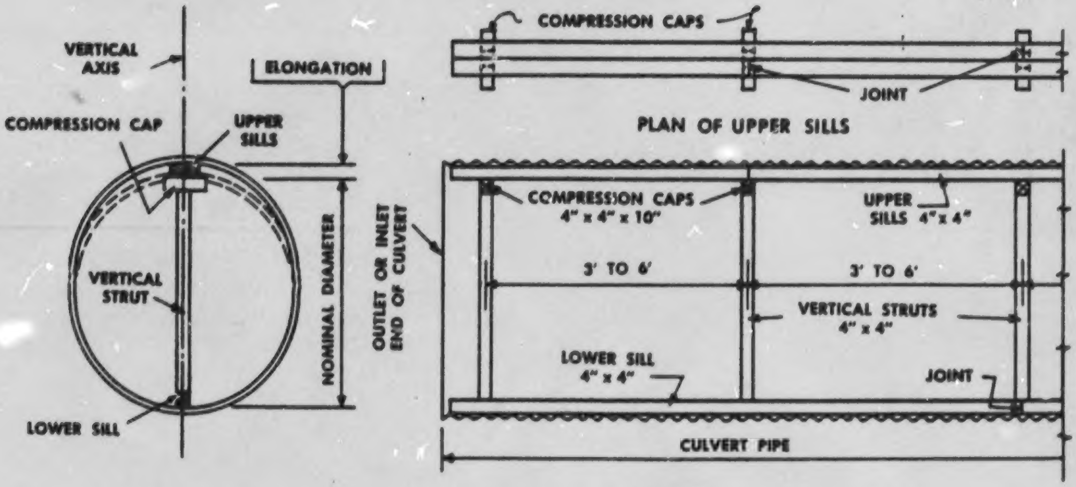


Figure 4-12. Details of strutting equipment and materials.


VERTICAL AXIS
ELONGATION
COMPRESSION CAP
UPPER SILLS
VERTICAL STRUT
NOMINAL DIAMETER
LOWER SILL
COMPRESSION CAPS
JOINT
PLAN OF UPPER SILLS
OUTLET OR INLET END OF CULVERT
COMPRESSION CAPS 4" x 4" x 10"
UPPER SILLS 4" x 4"
3' TO 6'
3' TO 6'
VERTICAL STRUTS 4" x 4"
LOWER SILL 4" x 4"
JOINT
CULVERT PIPE

END ELEVATION

LONGITUDINAL SECTION

NOTE: CULVERTS 60" TO 72" IN DIAMETER SHALL BE ELONGATED 2" ALONG THE VERTICAL AXIS DIMENSION. CULVERTS 84" IN DIAMETER SHALL BE ELONGATED 2½".

Figure 4-13. Strutting diagram showing end and longitudinal views.

TABLE 4-3. *Strut Spacing, Using 4- by 4-Inch Timbers With Transverse Compression Caps*

Pipe diameter (inches)	Fill heights in feet:		
	Up to 20	20-30	30-40
	Spacing of struts in feet		
60	6	6	5
66	6	6	4.5
72	6	5	4
78	6	4.5	3.5
84	6	4	3

c. **Installation of strutting.** Not less than four men must work together, proceeding as follows:

(1) Distribute the prepared sills, struts, and other members throughout the entire length of pipe as near as possible to where they will be needed.

(2) Lay the bottom sills in their proper position, with additional bearing blocks alongside to form bases for the jacks.

(3) Place the first jack on the bottom sill just ahead (toward the opposite end of the culvert) of where the first vertical strut will be placed.

(4) Place the second jack just in back of where the second vertical strut will be placed.

(5) Hold the upper sills in place while placing jack struts on the jacks. Use a carpenter's level to plumb all struts.

(6) Place a compression cap between the jack strut and the upper sills.

(7) Apply pressure evenly on both jacks.

(8) Insert the vertical strut and compression cap as soon as jack pressure has made enough room for them to fit between the upper and lower sills. Release the jack pressure and remove jack, jack strut, and compression cap. Be careful to prevent the

jacks from slipping out of place while pressure is being applied, and to keep the vertical struts in alinement when releasing jack pressure.

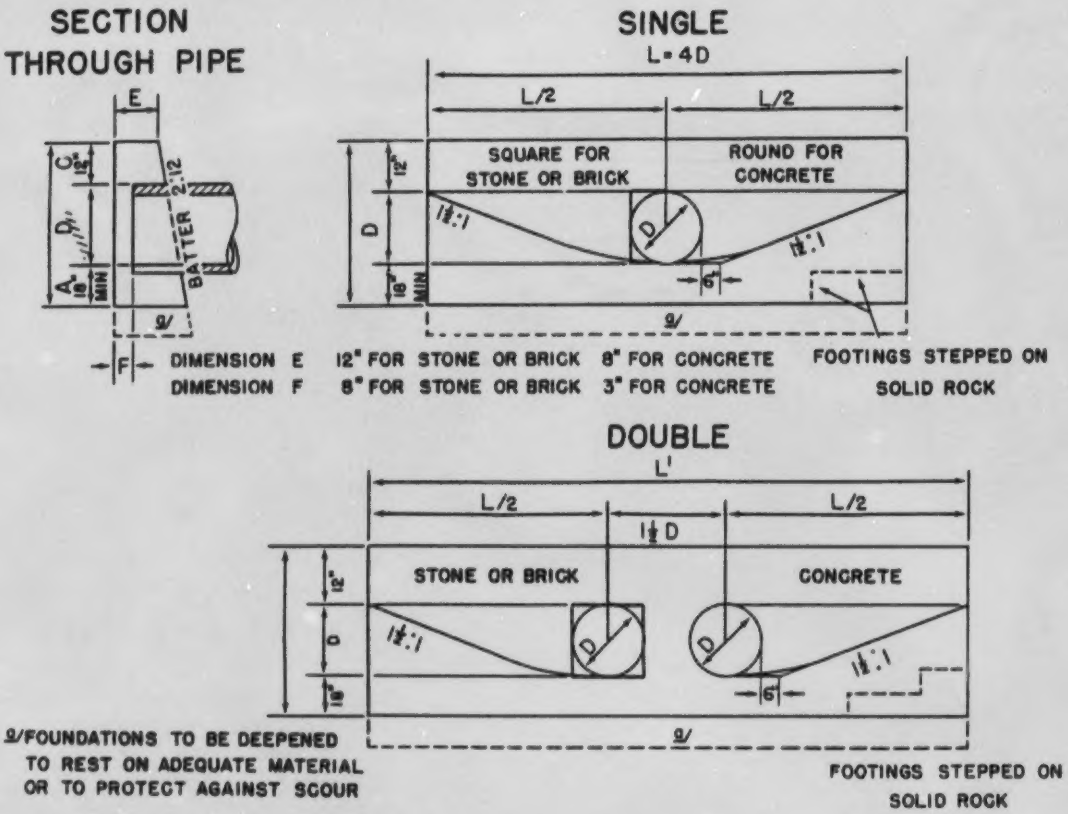
(9) Remove the first jack and place it just ahead of the position where the third vertical strut will be placed.

(10) Set the third jack strut, compression cap, and jack before removing the second jack and setting up the fourth jack strut.

(11) Repeat this procedure for the full length of the culvert.

4-9. HEADWALLS AND WINGWALLS

Headwalls and wingwalls are constructed to prevent or control erosion, guide water into the culvert, reduce seepage, and hold the ends of the culvert in place. These structures are expensive both as to time and materials. Consequently, on the inlet end the pipe culvert should be extended so that a minimum height and length of headwall are required. As a general rule, headwalls can be omitted on the outlet end of pipe culverts except on steep grades, where they are needed to hold culvert sections in place. Headwalls should not protrude above shoulder grade and should be located at least 2 feet outside the shoulder, so they will not be a traffic hazard. If headwalls or wingwalls are not used, the culvert will have to be extended to at least 2 feet beyond the toe of the fill. Headwalls and wingwalls should ordinarily be constructed of materials as durable as the culvert, but sandbags or rubble may be used for temporary installations. See figure 4-14 for dimensions


SECTION THROUGH PIPE
E
C
12"
D''
A
18" MIN
BATTER 2:12
a/
F
DIMENSION E 12" FOR STONE OR BRICK 8" FOR CONCRETE
DIMENSION F 8" FOR STONE OR BRICK 3" FOR CONCRETE
SINGLE
L=4D
L/2
L/2
SQUARE FOR STONE OR BRICK
ROUND FOR CONCRETE
12"
D
18" MIN
D
1½:1
1½:1
6"
a/
FOOTINGS STEPPED ON SOLID ROCK
DOUBLE
L'
L/2
1½ D
L/2
STONE OR BRICK
CONCRETE
12"
D
18"
1½:1
1½:1
D
D
6"
a/
FOOTINGS STEPPED ON SOLID ROCK

a/FOUNDATIONS TO BE DEEPENED TO REST ON ADEQUATE MATERIAL OR TO PROTECT AGAINST SCOUR

Figure 4-14. Typical concrete, brick, and stone-masonry headwalls.

of typical concrete, brick-work, and stone-masonry headwalls. Log or timber headwalls or wingwalls may be used, as shown in figure 4-15. Timber headwalls and wingwalls are similar to timber retaining walls for bridge abutments. For walls less than 5 feet high, the wall may be made of 2- or 3-inch by 12-inch timbers supported by timber piles or posts. Where wingwalls are required to channelize water and prevent the washing out of headwalls, they should be built to fit site conditions. Their height should be sufficient to prevent spilling of embankment material into the waterway. Their top thickness will be the same as the top thickness of headwall to which they are attached. The embankment side is inclined 2 inches for each 12 inches of height, but the outside faces are kept plumb.

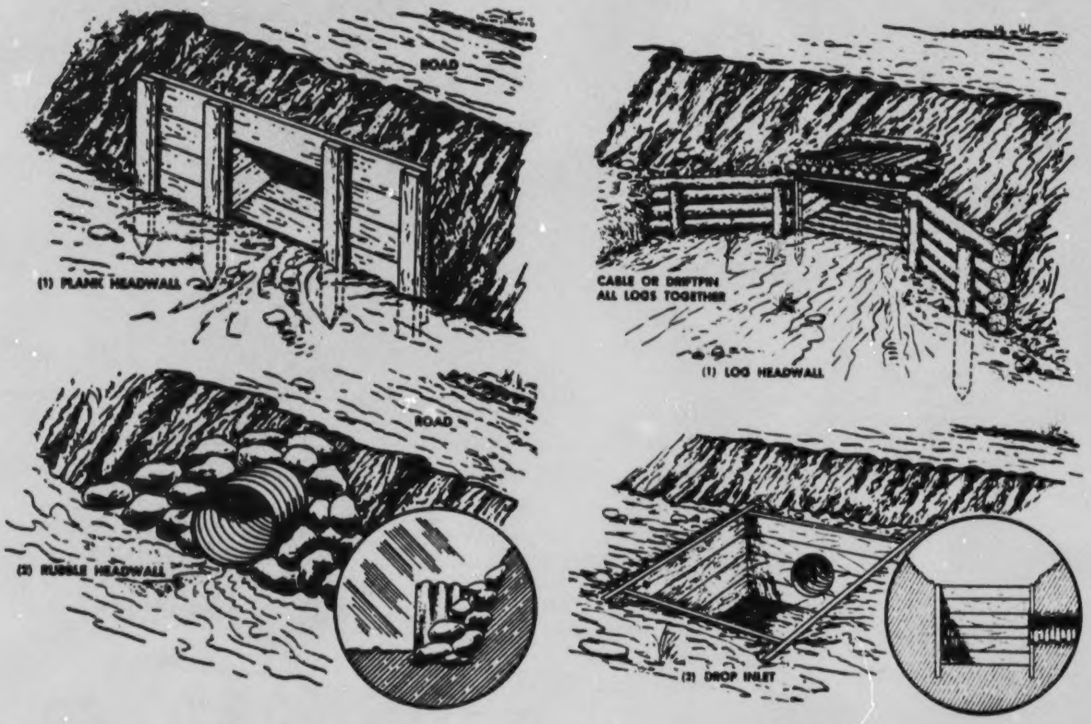


Figure 4-15. Headwalls and drop inlets for culverts.

Section II. PONDING AND CULVERT DESIGN

4-10. REASONS FOR PONDING

The rainfall section of lesson 1 stated that military drainage structures are seldom, if ever, designed to discharge the worst storm on record. For this reason it may be assumed that a storm more severe than the design storm may occur and overload the drainage system. Since most military drainage structures will be overloaded at one time or another during their useful life, it is usually a good procedure to design the area around a culvert or drain inlet to take care of a certain amount of ponding. In some cases, for economy, a drainage engineer may deliberately specify a system which cannot immediately take care of even the design storm. When this procedure is followed, sufficient ponding areas must be included in the overall plan so that inundation of vital areas does not occur. In this case, the excess water is merely stored until the intensity of the storm decreases to the extent that the drains can handle the water. As a general rule, drainage systems on military installations are designed to take care of the runoff from the design storm without ponding. For reasons previously mentioned, however, some provision should be made for ponding to take place in those areas where inundations for a period of time will not affect the operational duties of the installation.

4-11. PONDING SPECIFICATIONS

The following specifications are generally followed in the design of ponding areas for military installations.

a. The edge of ponding areas must be at least 75 feet from the pavement edge.

b. The pond must be drained before damaging infiltration of the subgrade can occur. The actual time during which ponding is allowable depends upon the condition and type of soils found in the ponding area. Generally speaking, this period will be about 4 hours after the storm begins for most of the soils encountered in practice.

4-12. PONDING-DESIGN ASSUMPTIONS

In designing a ponding area, certain assumptions are made to simplify the calculations and, at the same time, retain satisfactory accuracy. The following are the assumptions generally made:

a. A culvert discharges at its design capacity even before enough runoff has accumulated behind the pipe to produce a pond.

b. An increase in head because of ponding does not increase the discharge capacity of a culvert.

c. The length of flow is measured to the middle or average-elevation contour of the maximum ponding area attained at any time during the storm.

4-13. PERMISSIBLE VOLUME

a. Volume of permissible ponding is generally determined by the area available for such ponding and the relative elevations of this area and the surrounding areas. A contour map showing the final grading plan is required to compute the volume of permissible ponding. By inspection, a contour line may be selected that will provide a ponding area located a safe distance from the pavement. Ponding volumes may be computed from the contour map by the "average end area method", where the average of the areas, in square feet, enclosed by two adjacent contour lines is multiplied by the contour interval in feet.

$$V = \frac{(A + B)}{2} \times b, \text{ in which}$$

V = volume in cubic feet

A = area of one contour in square feet

B = area of the next contour in square feet

b = vertical distance, in feet, between contours (contour interval)

b. As an example of computing volume for ponding, consider the contours shown in figure 4-16. It has been determined that water can be safely ponded to the 66-foot contour line. The bottom of the inlet end of the culvert is at elevation 62.0 feet. A planimeter was used to determine the total area enclosed by each contour line. The 66-foot contour line encloses 25,000 square feet. The 64-foot contour line encloses 10,000 square feet. It should be noted that the contours are concentric — the 66-foot contour line area includes the area bounded by the 64-foot contour line. Therefore:

$$\text{Volume 62-64} = \frac{10{,}000 + 0}{2} \times 2 = 10{,}000 \text{ cu ft}$$

$$\text{Volume 64-66} = \frac{25{,}000 + 10{,}000}{2} \times 2 = 35{,}000 \text{ cu ft}$$

Total volume of the ponding area 10,000 + 35,000 = 45,000 cu ft

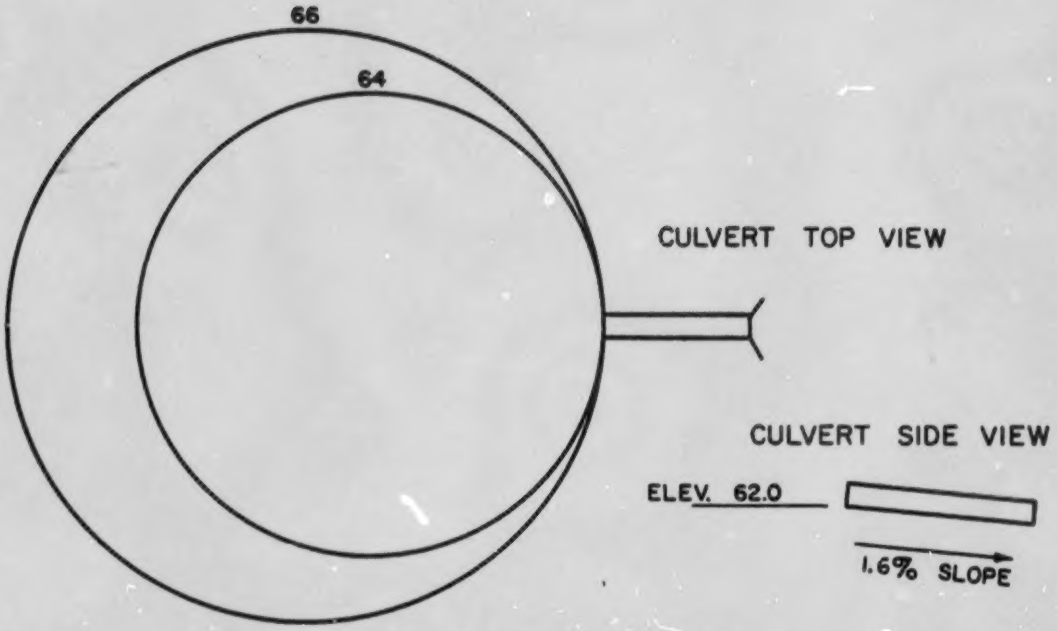


Figure 4-16. A ponding area. (See para 4-13b.)

c. As a further example of the computation of ponding volumes by the "average end area method", consider figure 4-17. Assume now that the ponding area is allowed to extend to the 68-foot contour line and determine the volume of the pond. The 68-foot contour line encloses a total area of 30,000 sq ft.

Therefore:

Volume 62-64 = 10,000 cu ft (from preceding example)

Volume 64-66 = 35,000 cu ft

$$\text{Volume 66-68} = 2 \times \frac{30{,}000 + 25{,}000}{2}$$

= 55,000 cu ft

Therefore:

Total volume available for ponding will be 10,000 + 35,000 + 55,000 = 100,000 cu ft if the ponding area extends to the 68-foot contour line.

4-14. RUNOFF CURVES

In order to determine the amount of water an area will contribute to a pond, a cumulative runoff curve must first be plotted. The following example shows how such a curve is prepared.

a. **Problem.**

(1) **Given:** The weighted equivalent length of the area drained is found by the Corps of Engineers' method (lesson 2A, para 2A-5) to be 100 feet. The design storm is 2.2 inches per hour. The area drained consists of 10 acres with an infiltration rate of 0.8 inch per hour and 20 acres with an infiltration rate of 0 inches per hour.

(2) **Required:** Prepare a cumulative runoff curve based on the data given.

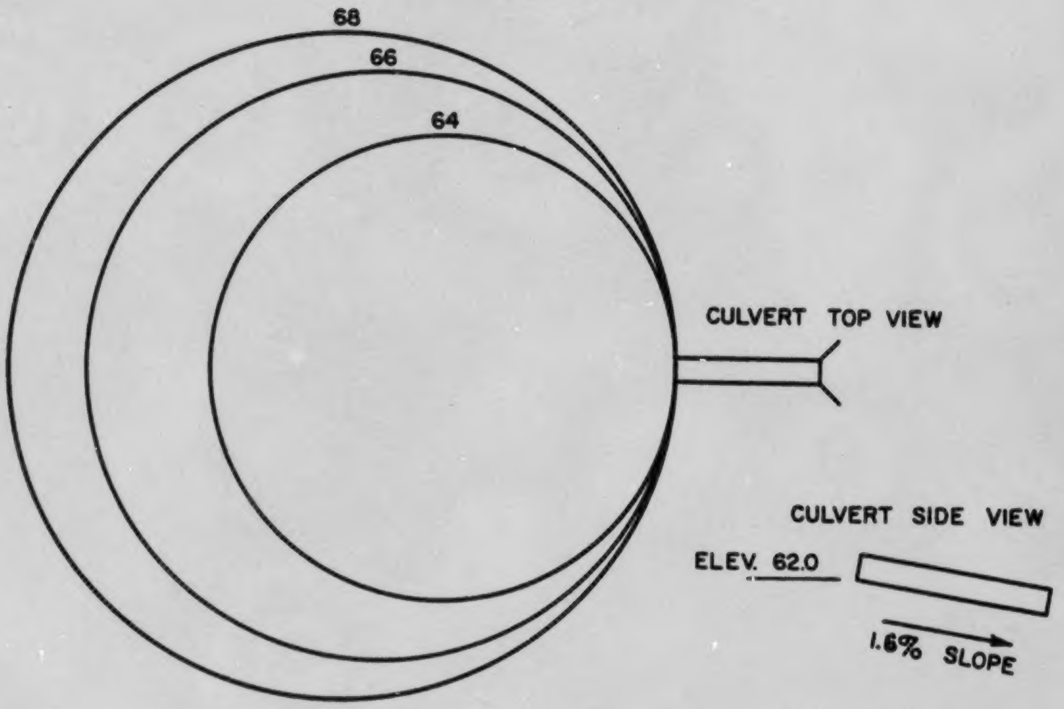


Figure 4-17. A ponding area. (See para 4-13c.)

b. **Tabulated data.** All the data needed to plot a cumulative runoff curve is shown in table 4-4. The method of preparing this tabulation may best be shown by explaining how each of its columns is compiled.

(1) Column 1 is a tabulation of time in minutes. Any similar combination of time increments can be used as long as enough properly spaced points are obtained to plot a smooth curve. The cumulative runoff curve is constructed by plotting time in minutes (col 1) against volume in cubic feet (col 6).

(2) Column 2 lists the rate of flow per acre that has been delivered to the pond during the time interval shown in column 1. In this case the design storm was given as 2.2 inches per hour. The weighted supply rate is found to be 1.93 inches per hour. The closest supply curve is 2.0. Using the supply curve number 2.0 (annex A-1 , the delivery rate for a 100-foot equivalent length for 10 minutes equals 3.2 cfs per acre, and for 20 minutes equals 3.5 cfs per acre. For periods of time greater than 80 minutes, the rate of flow can be found from figure 1-5, lesson 1, using the curve number corresponding to the supply rate.

(3) Column 3 is the size of the area drained in acres.

(4) Column 4 is the rate of runoff (Q) in cfs for the entire interval of time shown in column 1 and is obtained by multiplying columns 2 and 3 ($Q = Q/A \times A$). For 10 minutes $Q = 3.2$ cfs per acre × 30 acres or 96 cfs.

(5) Column 5 is the time in seconds. For 10 minutes, for example, column 5 would be equal to 10×60 or 600 seconds.

(6) Column 6 is the quantity of water that has been supplied to the pond for the period of time given in column 1, and is ob-

tained by multiplying column 4 by column 5. For the first 10 minutes:

Column 6 = (Column 4) (Column 5)

Column 6 = (96) (600) = 57,600 cu ft

After 20 minutes from the start of the rainfall have elapsed, the volume of water in the pond would be equal to (105) (1,200) or 126,000 cu ft if no water was released from the pond.

c. **Preparing the cumulative-runoff curve:** The cumulative-runoff curve is obtained by plotting volumes (col 6) on the vertical axis and time in minutes (col 1) on the horizontal axis. The cumulative-runoff curve for the data listed is shown in figure 4-18.

4-15. ANALYSIS OF THE CUMULATIVE RUNOFF CURVE

Runoff curves are analyzed as follows:

a. Assume that the safe ponding area equals 100,000 cu ft (fig 4-17), and that a 36-inch CMP culvert is installed at a 1.6 percent slope.

b. From Annex A-4, a 36-inch CMP culvert at 1.6 percent slope discharges 40 cfs. The assumption is made that the pipe always discharges at rated capacity; therefore the cumulative volume discharged by the pipe is a straight-line function. Hence, determine the volume that the pipe will discharge in any time interval and plot this cumulative discharge volume on the cumulative runoff graph. Connect this point to the origin with a straight line. For example, the 36-inch pipe discharges at the rate of 40 cfs. In 100 minutes, the pipe will pass, (40) (6,000) = 240,000 cu ft. This point is plotted on figure 4-18 and a straight line is drawn from the origin through this point until it intersects the cumulative-runoff curve. This cumulative-discharge-volume line intersects the cumulative runoff curve at about 104 minutes. At 104 minutes, 250,000 cubic feet of water have been supplied to the drainage area by the rainstorm while 250,000 cubic feet of water have been discharged through the 36-inch culvert. Therefore, a ponding condition is no longer present.

c. Now it is known how long the pond will exist behind the inlet. The next item to cover should be the determination of whether or not the ponding area is large enough. If figure 4-18 is referred to again, it will be seen

TABLE 4-4. *Tabulation of Cumulative-Run Data*

(1) Time (min)	(2) Q/A	(3) A	(4) Q (cfs)	(5) Time (sec)	(6) Volume (cu ft)
10	3.2	30	96	600	57,600
20	3.5	30	105	1,200	126,000
30	3.0	30	90	1,800	162,000
40	2.7	30	81	2,400	194,000
50	2.3	30	69	3,000	207,000
60	2.0	30	60	3,600	216,000
90	1.5	30	45	5,400	243,000
120	1.2	30	36	7,200	259,000
180	0.9	30	27	10,800	292,000

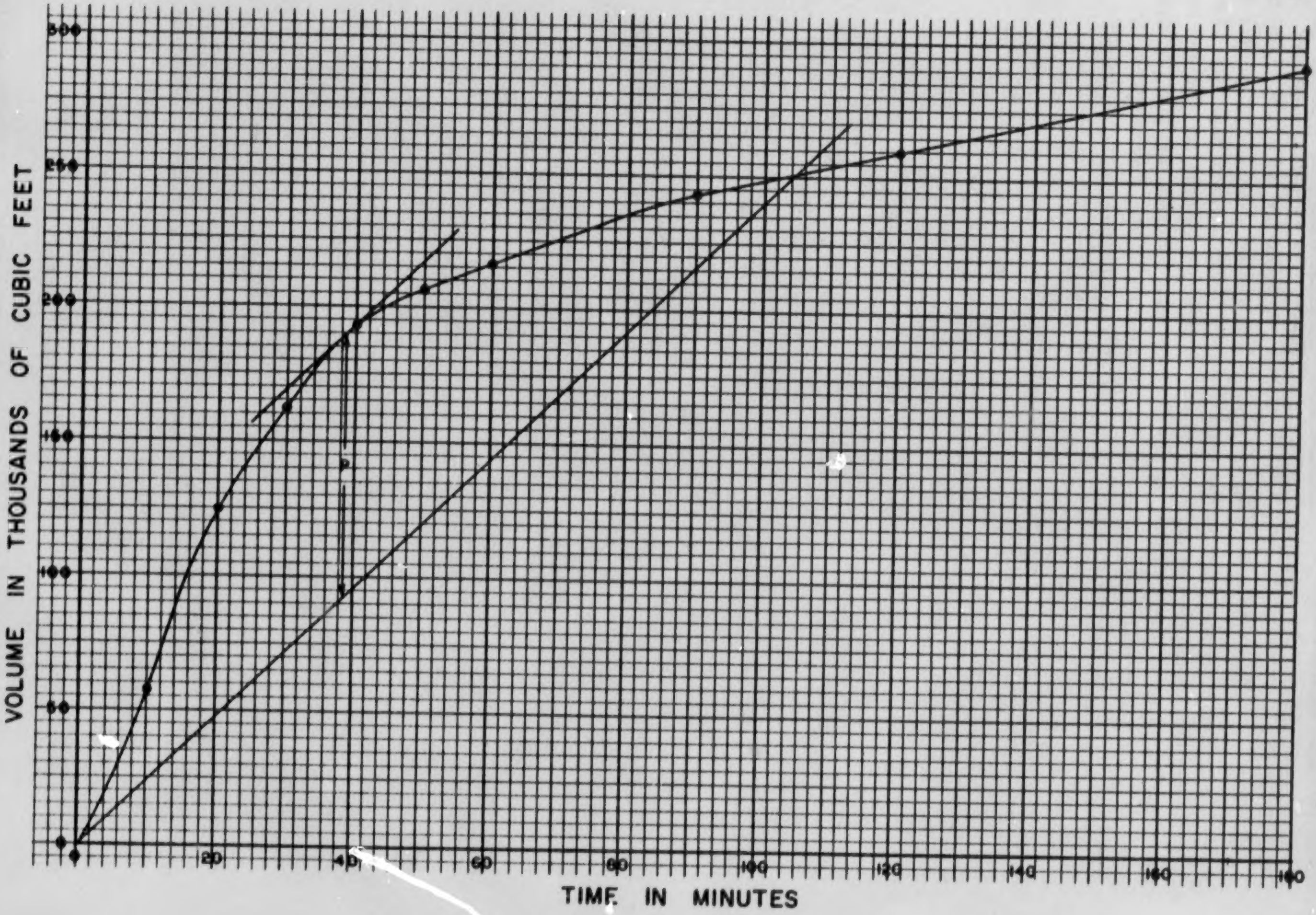


Figure 4-18. Cumulative-runoff curve.

that the greatest vertical distance between the cumulative runoff curve and the cumulative-discharge-volume line is shown by the line P. The line P represents the maximum volume of water that has ponded behind the culvert. If the same vertical scale is used in measuring this line P, it will be seen that the maximum ponding volume will be 96,000 cubic feet. At 39 minutes, the cumulative supply curve shows that 192,000 cubic feet of water have been supplied by the rainstorm to the drainage. At the end of 39 minutes, the 36-inch culvert has theoretically been able to discharge 93,600 cubic feet. Therefore, the difference between the quantity supplied (192,000 cu ft) and the quantity discharged (93,600 cu ft), or 98,400 cubic feet must still be in the pond. In view of the fact that our safe ponding volume is 100,000 cubic feet as shown in figure 4-17, the 36-inch CMP is satisfactory.

4-16. ADVANTAGES OF PONDING

In general, ponding will prove useful as an economy measure or as an added safeguard against the effects of storms more severe than the design storm. Its primary use as an economy measure is to reduce the size of culvert or pipe necessary to handle the runoff. Ponding will appreciably reduce pipe sizes for areas that have a short time of concentration. For longer times of concentration, ponding will have little or no effect on pipe sizes. The use of ponding as an economy measure is often restricted by the area available for ponding. This area should not only be sufficient to satisfy the requirements of the design storm, but should have enough reserve capacity to take care of storms of greater than design intensity. Facilities for ponding should be coupled with the initial grading operations, if possible, to secure the most efficient use of the men and machinery involved.

4-17. CULVERT TYPES

CMP, concrete pipe, box culverts, and improvised pipe culverts are the main types of culverts used in the theater of operations.

a. **CMP.** Corrugated metal pipe is the most common pipe material used for culverts in the theater of operations. CMP is a standard item issued in sizes from 12-inch to 48-inch diameter in 6-inch increments plus 60-inch and 72-inch diameters. Pipe culverts are commonly used to provide openings up to 28 square feet (72-inch diameter), and multiple pipes may be used to provide larger openings.

b. **Concrete pipe.** Concrete pipe is a common culvert material and may be procured locally or manufactured in the theater of operations by the construction unit if conditions warrant use of this material. Concrete pipe, for a given size, has a greater capacity than CMP; however, its greater weight and greater discharge velocity are factors which should be considered in choosing pipes for a culvert.

c. **Box culverts.** Box culverts of timber, logs, or concrete are often constructed when standard pipes cannot be obtained. Box culverts are used to provide waterway openings from 12 to 144 square feet, and multiple boxes may be used for larger openings.

d. **Improvised pipe culverts.** Improvised pipe, such as 55-gallon oil drums (23-inch diameter) welded end to end or civilian water or sewer pipes, where readily available, often save time and transportation if used as a culvert. These materials should be checked for load-bearing capacity.

4-18. CULVERT HYDRAULIC-DESIGN PRINCIPLES

The discharge capacity (Q) of a given culvert is controlled by one or more of the following factors: the elevation of the water at the culvert inlet; the hydraulic gradient (S) of the culvert; the length (L) of the culvert, and the elevation of the tailwater at the culvert outlet. Except for drop inlets, the type of inlet is not generally considered in military culvert design, but it should be remembered that the discharge capacity of a culvert will be increased, particularly in short culverts on steep slopes, by smooth-transition type of inlet.

a. **Culvert inlet water elevation.** For roads, airfields, and railroads where extensive ponding at the inlets of culvert is not desirable, culverts are usually designed to utilize the smallest size and least number of available pipes that have a total discharge capacity sufficient to pass the peak runoff from the design storm without allowing the water surface at the inlet to become higher than the top of the inlet.

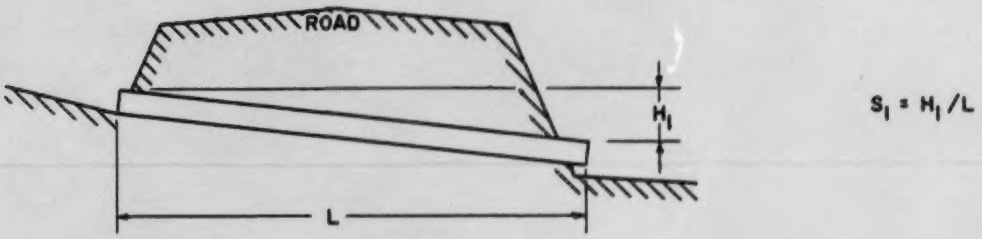
b. **Culvert hydraulic gradient.** The hydraulic gradient or slope (S) of a culvert is one of the more important controls of culvert discharge capacity. For culverts that are designed to avoid ponding and are unsubmerged at the inlet and outlet, the hydraulic gradient can be assumed or equal to the longitudinal slope of the culvert. The hydraulic gradient (S) for any culvert can be satisfactorily estimated as the slope in feet per foot that is calculated by dividing the head (H) on a culvert by the length (L) of the culvert ($S = \frac{H}{L}$). Head is the difference in elevation between: (a) each end of a culvert if the inlet and outlet are not submerged; (b) the water surface directly above the inlet and the top of the outlet if the inlet is submerged and the outlet is not submerged; and (c) the water surface directly above the inlet and the water surface directly above the outlet if both the inlet and outlet are submerged. The head and hydraulic gradient are illustrated in figure 4-19.

c. **Critical slope.** For a given size (A) of culvert and a given head (H) on the culvert, the discharge capacity of a culvert will increase as the hydraulic gradient increases until the hydraulic gradient becomes equal to or greater than the critical slope (S_c). As the hydraulic gradient is increased beyond critical slope, the discharge of culvert remains constant, the area decreases since the pipe does not flow full, and the velocity of flow in the culvert increases by $V = Q/A$. Critical slope is the minimum slope of the hydraulic gradient that will permit maximum discharge. Culverts should be designed to have hydraulic gradients about equal to critical slope whenever possible. Equations for approximating the critical slope for culverts and Manning's "n" for various types of pipe are given in table 4-5.

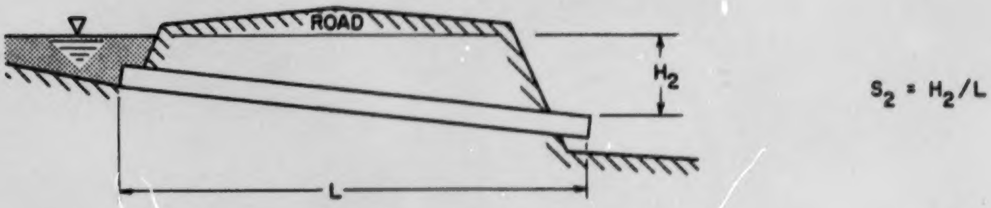
TABLE 4-5. *Roughness Coefficients and Equations for Approximate Critical Slope for Pipe Culverts*

Type of culvert	Manning's roughness coefficient (n)	Equation for approximate critical slope in percent (S_c)
Corrugated metal pipe or pipe arch	0.024	$S_c = 2.66/D^{1/3}$
25% asphalt paved	0.021	$S_c = 2.04/D^{1/3}$
50% asphalt paved	0.018	$S_c = 1.65/D^{1/3}$
100% asphalt paved	0.013	$S_c = 0.79/D^{1/3}$
Concrete pipe or box	0.013	$S_c = 0.79/D^{1/3}$
Vitrified clay pipe	0.013	$S_c = 0.79/D^{1/3}$
Clean cast-iron pipe	0.013	$S_c = 0.79/D^{1/3}$
Smooth steel pipe	0.011	$S_c = 0.56/D^{1/3}$
Planned-wood pipe	0.012	$S_c = 0.68/D^{1/3}$
Rough-lumber pipe	0.013	$S_c = 0.79/D^{1/3}$

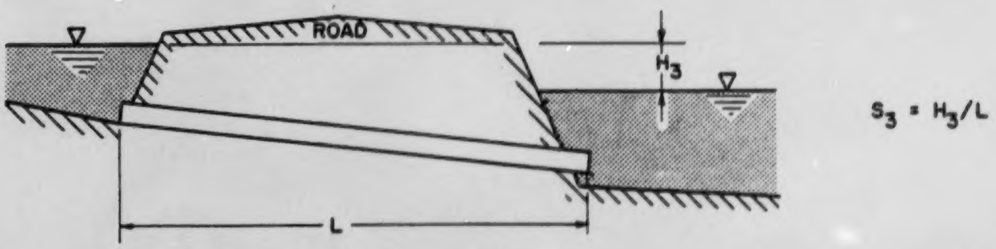
NOTE: To determine critical slope in percent, use the pipe diameter in feet.


ROAD
H_1
L
$S_1 = H_1/L$

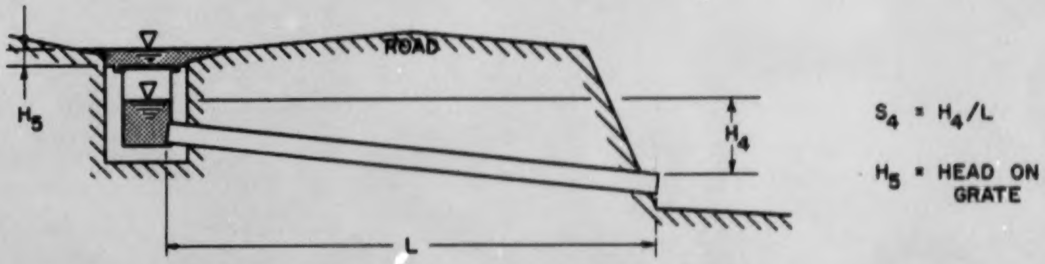
(a) INLET AND OUTLET UNSUBMERGED.


ROAD
H_2
L
$S_2 = H_2/L$

(b) INLET SUBMERGED AND OUTLET UNSUBMERGED.


ROAD
H_3
L
$S_3 = H_3/L$

(c) INLET AND OUTLET SUBMERGED.


ROAD
H_5
H_4
L
$S_4 = H_4/L$
H_5 = HEAD ON GRATE

(d) DROP INLET CULVERT -- INLET SUBMERGED AND OUTLET UNSUBMERGED.

Figure 4-19. Culvert hydraulic gradient (S) and head (H).

d. Culvert outlet tailwater elevation. Whenever possible, culverts should be designed to have a "free" or unsubmerged outlet since a submerged outlet tends to restrict the flow of water through the culvert and result in ponding at the inlet. To insure a "free" outlet, the end of the culvert outlet should be placed at or above the expected elevation of the tailwater surface in the channel at the culvert outlet.

4-19. CULVERT-DESIGN PROCEDURE

a. Determine the maximum rate of runoff (Q) that the culvert must drain.

b. Determine the maximum permissible discharge velocity (V_{max}) from table 4-6, or annex A-3.

TABLE 4-6. *Maximum Permissible Velocities (V_{max})*

Ditch lining	V_{max} (in fps)
Concrete or bituminous	20
Grouted riprap, hand placed	15
Ungrouted riprap, hand placed	10
Natural earth, no vegetation	
Uniform sand	1 - 2
Well-graded sand	1 - 2
Silty sand	2 - 3
Clays	3 - 5
Gravel	5 - 8
Natural earth with vegetation	
Average turf	
Erosion-resistant soil	4 - 5
Easily eroded soil	3 - 4
Dense turf	
Erosion-resistant soil	6 - 8
Easily eroded soil	5 - 6

c. Determine the sizes and strengths of materials available for the culvert.

d. Draw a cross section of the fill or embankment showing elevation, the inlet and outlet channels, and the culvert slope. The culvert slope (S)) should be slightly less than the critical slope (table 4-5) for the diameter and type of pipe to be used and should provide the type of inlet and outlet desired.

e. Calculate the depth of fill at the outside edge of the shoulder from the cross section. Select only the pipes for which adequate cover is available.

f. Determine the roughness coefficient (n) of the culvert material from table 4-6.

g. Special considerations.

(1) CMP or concrete pipe culverts with inlet unsubmerged. From annex A-4 determine the pipe capacity (Q_p). Calculate the number of pipes required (number = Q/Q_p).

(2) Other types of pipe culverts with inlet unsubmerged. Calculate the required diameter (D) or slope (S) of a circular pipe flowing full from Manning's formula.

(3) Design of box culverts with inlet unsubmerged. The characteristics of flow through square or rectangular culverts with the same slope, culvert lining, inlet, and outlet do not differ significantly from flow through round conduits. Box culvert sizes can be determined by computing the cross-section area required for a circular pipe and designing a box culvert of the same material as the pipe and with the same cross-section area.

(4) Culverts with a submerged inlet. Determine the size of pipe, pipes, or box culvert required to drain in the case of ponding.

h. Determine graphically, or mathematically calculate, the length required.

i. Determine the head as illustrated in figure 4-19.

j. Compute the discharge velocity (V) by using Manning's formula or annex A-4. If the discharge velocity is greater than the maximum permissible velocity, either decrease the slope of the culvert or select pipe of a smaller diameter.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space below the question. When you have finished answering all the questions for this lesson, compare your answers with those given in the back of this booklet. Do not send in your solutions to these review exercises.

1. A ditching machine will normally be able to make better progress if it can travel downgrade while digging. Under what conditions would it be better to dig while traveling upgrade? (4-1)

2. To prevent water from standing in a drainage ditch and seeping into the ground, what minimum grade should be maintained? (4-2)

3. For soil erosion to occur due to flowing water, what condition must exist between the soil and water? (4-3)

4. Check dams should not be employed to prevent erosion in drainage ditches when the grade of the ditch exceeds what percent slope? (4-4)

5. What is the minimum length apron you should construct on the downstream side of a check dam if the vertical drop between the bottom of the weir notch and the top of the apron is 3 feet? (4-4a)

6. What should be the distance between check dams in a drainage ditch if you wish to reduce the water slope from 4 to 2 percent using check dams with a height of drop of 2 feet? (4-4a)

7. In designing the weir notch for a check dam, what safety measure is taken? (4-4b)

8. A weir is to be placed in a drainage ditch carrying a flow of 8 cfs. The length of the weir notch is to be 2½ feet. Using the formula $Q = CLH^{3/2}$ and a constant of 3, find the depth of water flow in the weir notch. (4-4b)

9. The capacity of a specific grate is dependent upon what factor? (4-5)

10. What capacity in cfs would a 24" x 24" grate have under a 1.4 ft head of water? (4-5, table 4-2)

11. At what angle to the centerline of the road should you place a ditch-relief culvert if the road is on a sidehill cut and steeply graded? (4-6a)

12. Why is it generally desirable to place the bottom of the outlet end of a culvert at the elevation of the surface of a stream rather than below the surface? (4-6b)

13. If possible, culvert slope should be kept the same throughout its length. If it is necessary to change the slope, where should the steepest sloping section be located? (4-6c)

14. When multiple-pipe culverts are installed what is the minimum distance they must be separated? (4-6d)

15. In the preparation of the foundation for a pipe culvert, why is it good practice to convex the foundation upward along the culvert centerline? (4-6e)

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16. In backfilling a culvert, the fill material must be hand or mechanically tamped to what elevation? (4-6f)

17. What is the minimum amount of cover required over a corrugated metal pipe culvert used in a road? (4-6g)

18. For a cut section the length of culvert required is normally found by measuring the distance between what two points? (4-7a)

19. What minimum diameter pipe should be used if the length of culvert required is over 30 feet? (4-7a)

20. In determining the strength of culvert required, what loads must be considered? (4-7b)

21. What is the purpose for strutting nestable corrugated metal pipe before backfilling? (4-8)

22. When strutting a 72" diameter culvert, how much elongation should you allow for? (4-8a, fig 4-13)

23. Using 4" x 4" timbers what strut spacing would you use for a 60" diameter culvert under a 25 ft fill? (4-8b, table 4-3)

24. What are the four functions of headwalls and wingwalls? (4-9)

25. What general rule do military installations follow in regard to making provisions for ponding by storm water? (4-10)

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26. In a certain area, it is found that ponding is permissible between the 60 and 65 foot contour lines. By use of a planimeter it is found that the 60 foot contour encloses 10,000 sq ft and the 65 foot contour encloses 50,000 sq ft. How many cubic feet of water can be ponded in that area? (4-13a, b)

27. What is the purpose of preparing a tabulation of cumulative-run data such as shown in table 4-4? (4-14b)

28. What is the purpose for preparing a cumulative runoff curve? (4-14)

29. If, on the same graph you plot a cumulative runoff curve, and also plot the cumulative discharge through the drainage pipe, what is significant about the point where these two lines intersect? (4-15b)

30. On the graph described for exercise 29, how can you determine the maximum amount of water that will be in the pond during the selected storm? (4-15c)

31. One of the advantages of ponding is economy in that it permits the use of smaller drainage pipes. What type of drainage area is particularly suitable to ponding for economic reasons? (4-16)

32. What is the most common pipe material used for culverts in the theater of operations? (4-17 a)

33. What rule should you follow in designing culverts for roads and airfields where extensive ponding at the culvert inlet is undesirable? (4-18a)

34. Define the "head" on a culvert under conditions of the inlet being submerged and the outlet not submerged. (4-18b)

35. Define the "critical slope" for a culvert. (4-18c)

LESSON 5

SUBSURFACE DRAINAGE

CREDIT HOURS	2
TEXT ASSIGNMENT	Attached memorandum.
MATERIALS REQUIRED	Charts 1 and 2.
LESSON OBJECTIVE	To teach you to recognize and correct conditions that require subsurface drainage.
SUGGESTIONS	Review paragraphs 1-14 through 1-21, lesson 1. Read the attached memorandum through rapidly to obtain a knowledge of its scope. Then read it through carefully, underlining the important points and objectives. Read the review questions at the end of the lesson. Study the lesson, searching for answers to the review questions, and write your answers in the spaces provided. Finally, check your answers with the answers given for this lesson at the back of this booklet. Review as necessary.

ATTACHED MEMORANDUM

5-1. SUBSURFACE-DRAINAGE CRITERIA

When surface failures show that the subsurface drainage is inadequate, it becomes necessary to determine whether or not a subsurface drainage system is necessary, and if so, what type to install. Generally speaking, subsurface drainage may be divided into three classes:

a. Base drainage generally consists of subsurface drain pipes laid parallel and adjacent to pavement edges with pervious material joining the base and the drain. (Figure 5-1 shows a typical section of a base-drain installation.) Base drainage is required where frost action occurs in the subgrade beneath the pavement and where ground water rises to the bottom of the base course as a result of natural conditions or from ponding of surface runoff. At locations where the pavement may become temporarily inundated and there is little possibility of the water draining from the base into the subgrade, base drainage will be required. Table 5-1 establishes the criteria to follow in these cases. Base drainage is also required at the low point of longitudinal grades in excess of 2 percent where the subgrade coefficient of permeability is less than 1×10^{-3} ft/min. The coefficient of permeability is a property of the soil and is defined as the discharge velocity at a unit hydraulic gradient. This value is determined experimentally, either by laboratory test or by an actual field test of the soil involved. It

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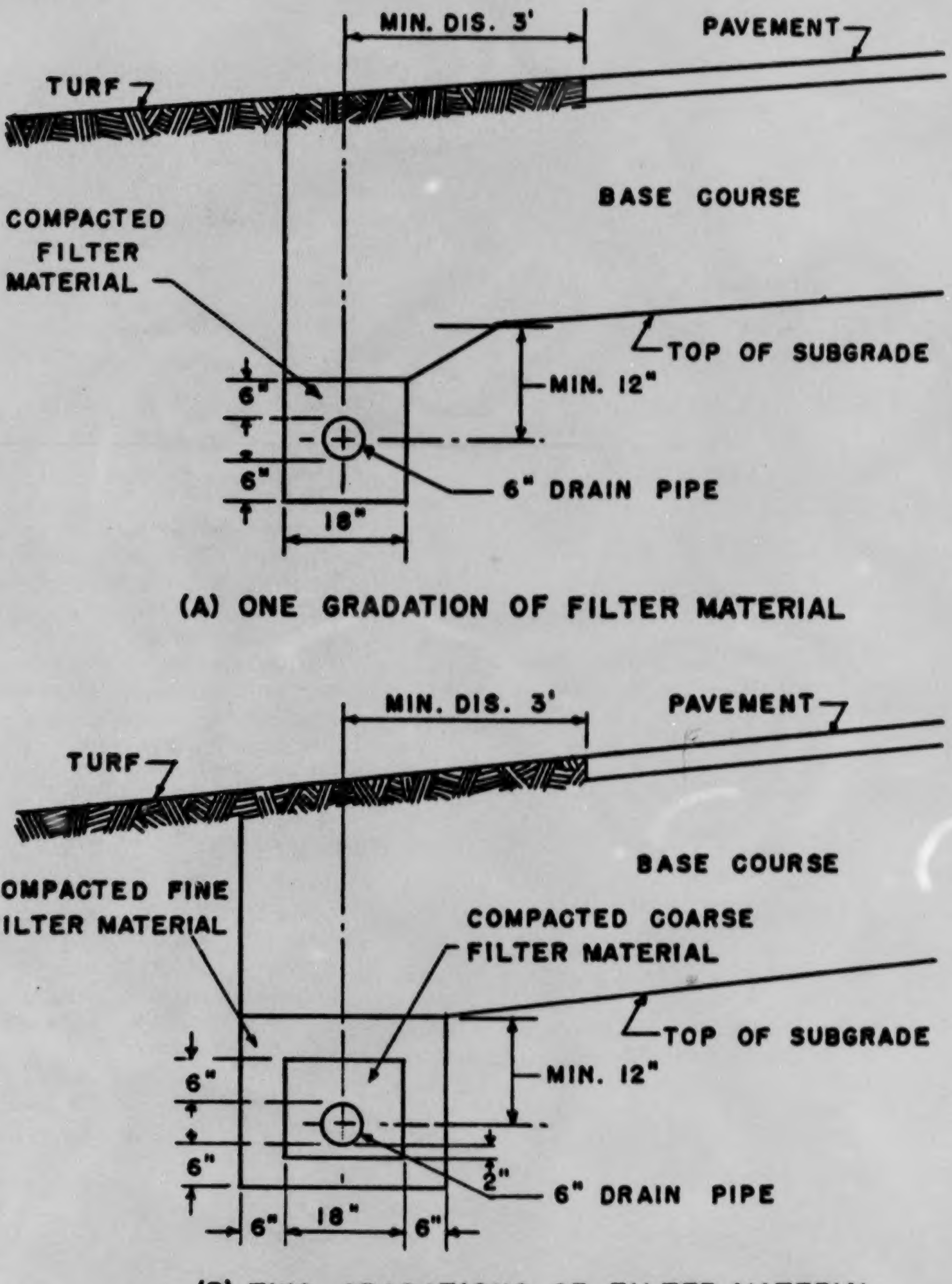
MIN. DIS. 3'
PAVEMENT
TURF
BASE COURSE
COMPACTED FILTER MATERIAL
TOP OF SUBGRADE
MIN. 12"
6"
6"
6" DRAIN PIPE
18"
(A) ONE GRADATION OF FILTER MATERIAL
MIN. DIS. 3'
PAVEMENT
TURF
BASE COURSE
COMPACTED FINE FILTER MATERIAL
COMPACTED COARSE FILTER MATERIAL
TOP OF SUBGRADE
MIN. 12"
6"
6"
2"
6" DRAIN PIPE
6"
18"
6"
(B) TWO GRADATIONS OF FILTER MATERIAL

Figure 5-1. Typical section of base-drain installation.

is expressed in units of velocity such as feet per minute (ft/min) or centimeters per second (cm/sec) and varies from 197 × 10^{-4} ft/min for gravel and gravel-sand mixtures to 197 × 10^{-10} ft/min for silts and clays.

TABLE 5-1. *Base Drainage Required if Subgrade Coefficient of Permeability is Smaller Than Stated Feet Per Minute and Inundation May Occur*

Depth to ground water (ft)	Coefficient of permeability less than:
Less than 8	1 × 10^{-5} ft/min
From 8 to 25	1 × 10^{-6} ft/min
Over 25	1 × 10^{-7} ft/min

b. Subgrade drainage is required when seasonal fluctuations of ground water may be expected to rise to a level less than 1 foot below the bottom of the base course. Figure 5-2 shows a typical example of a subgrade drainage section. Table 5-2 will serve as a guide for spacing drains. These drains, although similar to base drains, have a larger area of filter material in contact with the subgrade.

c. Intercepting drainage is required when seeping water in a pervious layer will raise the ground water locally to a depth of less than 1 foot below the bottom of the base course. Figure 5-3 shows a typical intercepting drainage layout.

5-2. DRAINAGE TECHNIQUES

There are various means which the engineering officer has available to handle any drainage situation. These are described below:

a. Increase the depth of base course so that the water table is a specified distance below the top of the base course. In most

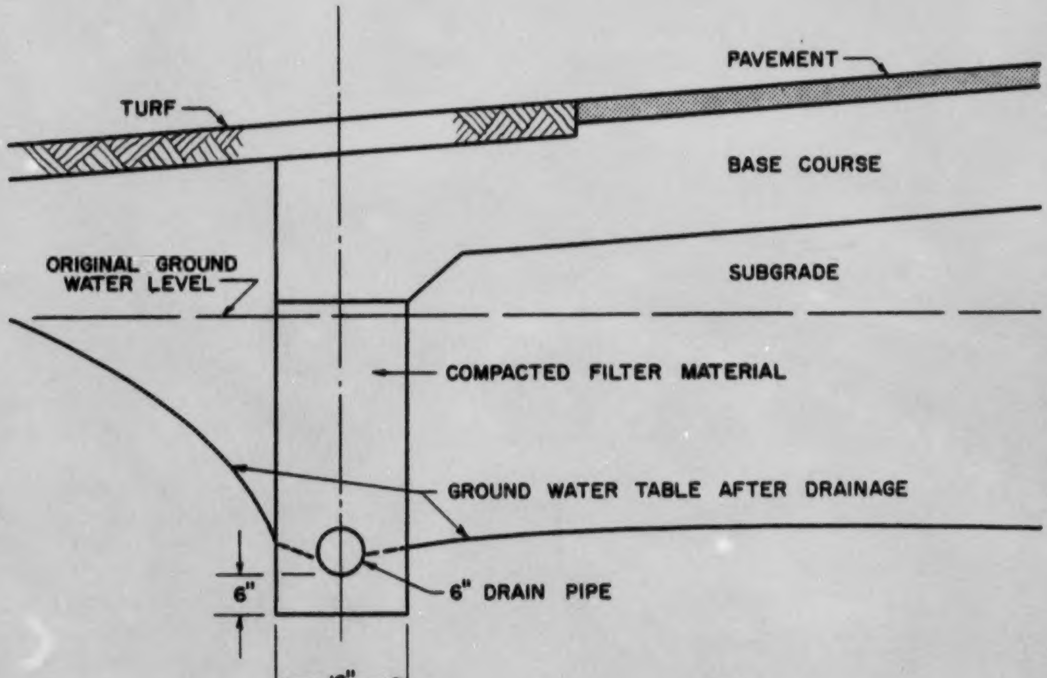
PAVEMENT
TURF
BASE COURSE
SUBGRADE
ORIGINAL GROUND WATER LEVEL
COMPACTED FILTER MATERIAL
GROUND WATER TABLE AFTER DRAINAGE
6"
6" DRAIN PIPE
18"

Figure 5-2. Subgrade-drainage details.

TABLE 5-2. *Approximate Depth and Spacing of Subgrade Drains in Various Types of Soils*

Soil classes	Percentage of soil separates			Depth of bottom of drain (feet)	Distance between subdrains (feet)
	Sand	Silt	Clay		
Sand	80-100	0-20	0-20	3-4 2-3	150-300 100-150
Sandy loam	50-80	0-50	0-20	3-4 2-3	100-150 85-100
Loam	30-50	30-50	0-20	3-4 2-3	85-100 75-85
Silt loam	0-50	50-100	0-20	3-4 2-3	75-85 65-75
Sandy clay loam	50-80	0-30	20-30	3-4 2-3	65-75 55-65
Clay loam	20-50	20-50	20-30	3-4 2-3	55-65 45-55
Silty clay loam	0-30	50-80	20-30	3-4 2-3	45-55 40-45
Sandy clay	50-70	0-20	30-50	3-4 2-3	40-45 35-40
Silty clay	0-20	50-70	30-50	3-4 2-3	35-40 30-35
Clay	0-50	0-50	30-100	3-4 2-3	30-35 25-30

cases, the required specification is that the ground-water level be at least 5 feet below the finished grade. This solution is feasible when:

(1) A gravity drainage system is impracticable.

(2) The condition to be corrected is of a small localized nature such as a narrow swamp crossing.

(3) There is an abundant supply of a good base-course material.

b. Another means of subsurface drainage is by deep, V-ditches. These ditches are easily built, are readily enlarged, and they provide positive interception of subsurface water before it reaches the area being protected. However, in many cases, such ditches are a traffic hazard and they are also subject to erosion. In those cases where right-of-way problems, traffic situations, and erosion difficulties make the use of open ditches impractical, it may be necessary to use a subsurface drainage system consisting of blind or "French" drains, or of perforated or open-joint piping. If the water level in natural drainage channels can be lowered, it may be possible to lower the ground-water level of the surrounding area, particularly if the surrounding soils are pervious.

c. Blind or French drains are constructed by filling a ditch or trench with broken

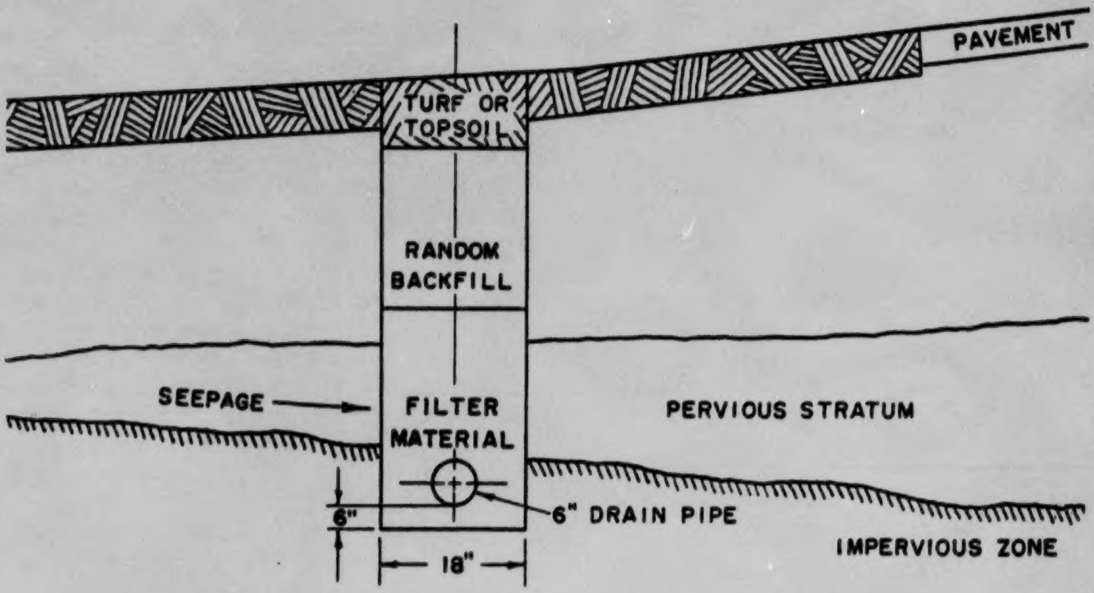

Figure 5-3. Typical intercepting drainage layout.

or crushed rock. The top surface of the rock may be left exposed so that the trench will act as a combination drain or the rock may be covered by a relatively impervious soil so that no surface water can penetrate. The latter is the general practice. In general, French drains are not recommended for permanent construction because they have a tendency to silt up with prolonged use. In theater-of-operations construction, however, such drains are often used as a substitute for perforated or open-joint pipe because of logistical limitations on piping or on filter materials suitable for use with such piping.

d. In cases where a V-type or other open-ditch-type drainage system is not practical, it may be necessary to resort to a subsurface piping system utilizing one of the many forms of pipe currently available.

(1) The most common form of subsurface piping is perforated pipe. In cases where the perforations do not extend completely around the circumference of the pipe, the pipe is generally laid with the holes down and with the joints closed. Materials used in the manufacture of this type of pipe are corrugated metal, cast iron, vitrified clay, and nonreinforced concrete.

(2) Bell and spigot pipes can be laid with open joints. Collars are not needed over the joints if the filter material has been properly designed. This type of pipe is generally made by vitrified clay, nonreinforced concrete, and cast iron.

(3) Skip pipe is designed so that water enters the pipe at bell and spigot joints which provide a gap around the bottom semi-circumference and a slot across the flat top surface of the pipe. Skip pipe is generally made of vitrified clay or cast iron.

(4) Porous-concrete pipe is laid with closed joints and collects water by seepage through the wall of the pipe. It should not be used where sulphated waters may cause disintegration of the concrete.

(5) Farm tile is laid with butt joints slightly separated to permit collection of water through the joint. Because of its low resistance to high impact loads, farm tile is not recommended for use on airfields. Mate-

rials commonly used in manufacture of the tile are clay or concrete.

e. The use of combination drains which attempt to handle both surface runoff and subsurface water by use of the same pipe system is not recommended. Surface runoff very often carries sediment and soil from the drained area into the system, with the result that flow stoppages occur. In view of this, subsurface drainage systems using some form of piping are generally sealed so that no surface runoff may enter. The only drainage system which will handle both surface runoff and subsurface water satisfactorily is the open channel or ditch.

5-3. PIPE-LAYING CRITERIA

There are essentially five different types of pipe available for use but they all should be laid in accordance with the following specifications:

a. Minimum slope of pipe is .15 percent or .15 feet in 100 feet. The elevation of a pipe at any particular location is generally specified by the invert elevation in which the invert is defined as the lowest point in the internal cross section of the pipe at one particular location. Figure 5-4 shows the invert location.

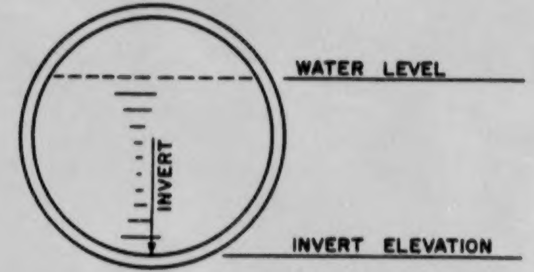

Figure 5-4. Invert location.

b. Manholes should be provided at intervals of not more than 1,000 feet, with a flushing riser between manholes. Flushing risers should also be installed at dead ends.

c. Pipe should be at least 6 inches in diameter with 6-inch pipe being used for all drains, except long intercepting lines and for extremely severe ground-water conditions where it may be necessary to use 8-inch or larger pipe.

d. Center of subgrade drains should be placed at a depth of not less than 1 foot below the bottom of the base course and not less than 1 foot below the ground-water table. Subgrade drains are generally required only at the edges of pavement areas where the soil is pervious and well draining. However, local ground-water conditions and base and subgrade soil characteristics may necessitate closer spacing of the drains. When the drain discharges into a culvert or any considerably larger pipe, it should discharge above the water level in the larger pipe. When the drain discharges into a pipe of equal or slightly larger size, it is generally better to bring the drain in above the main line and make a vertical connection between the two rather than join them at the same elevation. This procedure will prevent the water from backing up in the drainage pipe since these pipes are rarely flowing full.

e. When the impervious layer is at a reasonable depth, intercepting drains should be placed in the impervious layer below the intercepted seepage stratum. The quantity of water collected by an intercepting drain is difficult to determine, but in general, 6-inch pipe will prove sufficient for lengths up to 1,000 feet.

f. The piping system should be surrounded by at least 6 inches of suitable filter material selected in accordance with the principles outlined in paragraph 5-6. If it is not possible to secure a mechanical analysis of available filter materials, a good concrete sand with mechanical-analysis limits as shown in chart 1 may be used, because experience has shown that this is a satisfactory filter material for the majority of sandy, silty soils. Chart 1 is furnished with this subcourse.

5-4. VERTICAL WELLS

Vertical wells are sometimes constructed to permit trapped subsurface water to pass through an impervious soil or rock layer to a lower, freely draining layer of soil. If drainage is obstructed, additional wells are driven, or the pocket is drained with an easily maintained lateral subdrain system. Vertical wells are often used in northern latitudes, where deep freezing is common, to permit fast runoff from melting snow to get through the frozen soil and reach a pervious stratum. Under such conditions the bottoms of these wells are treated with calcium chloride or a layer of hay to prevent freezing.

5-5. FILTER MATERIAL

As has been previously stated, a layer of filter material approximately 6 inches in depth should be placed around all subsurface piping systems. The selection of the proper filter material is of great importance, since it determines to a large extent the success or failure of the drainage system. The improper selection of a filter material can cause the drainage system to become inoperative in one of three ways:

a. The pipe may become clogged by the infiltration of small soil particles.

b. Particles in the protected soil may move into or through the filters, causing instability of the surface.

c. Free ground water may not be able to reach the pipe.

5-6. PREVENTING FAILURES

In order to prevent the occurrence of any of the failures listed in paragraph 5-5, various crietria have been developed, which, based upon the mechanical-analysis soil curves, have proved effective in practice.

a. To prevent clogging the pipe with filter material moving through the perforations or openings, the following limiting requirements must be satisfied:

(1) For slotted openings:

$$\frac{\text{85-percent size of filter material}}{\text{slot width}} \quad \text{is greater than 1.2}$$

(2) For circular holes:

$$\frac{\text{85-percent size of filter material}}{\text{hole diameter}} \quad \text{is greater than 1.0}$$

b. To prevent the movement of particles from the protected soil into or through the filter or filters, the following conditions must be satisfied:

$$\frac{\text{15-percent size of filter material}}{\text{85-percent size of protected soil}} \quad \text{is less than or equal to 5}$$

and

$$\frac{\text{50-percent size of filter material}}{\text{50-percent size of protected soil}} \quad \text{is less than or equal to 25}$$

c. To permit free water to reach the pipe, the filter material must be many times more pervious than the protected soil. This condition is fulfilled when the following requirement is met:

$$\frac{\text{15-percent size of filter material}}{\text{15-percent size of protected soil}} \quad \text{is greater than or equal to 5}$$

d. The coefficient of uniformity (Cu) of the filter material should be less than 20 to prevent segregation of the material during placement. The coefficient of uniformity is defined by the following relationship:

$$\text{Cu} = \frac{\text{60-percent size of filter material}}{\text{10-percent size of filter material}}$$

e. It is possible to learn a great deal about the gradation characteristics of a particular soil by observation of the soil curves on the mechanical-analysis chart. Well-graded soils generally have a smooth grain-size curve with gradual changes of slope. Poorly graded uniform soils generally have a very steep grain-size curve. Skip-graded soils have a grain-size curve with a characteristic hump in it. The filter material will have a tendency to segragate during placement if it is skip-graded. The grain-size curves in chart 1 illustrate various gradation characteristics.

5-7. SELECTING FILTER MATERIAL

The filter material should be selected with the view toward simplest construction and lowest cost. To further this end it is desirable to use only one layer. If several layers of filter material are required, one layer should be confined to the region around the pipe openings and another layer placed between it and the protected soil, as shown in figure 5-1. The designer would proceed, in this case, by selecting a filter material to be placed around the pipe in accordance with the formulas in paragraph 5-6. The second filter material should be designed to protect both the inner filter material and the surrounding soils. In other words, the design of a multilayer filter for a subdrain system should proceed outward from the inside filter material to the subgrade soil being protected.

5-8. EXAMPLE OF FILTER DESIGN

You are to choose a suitable filter material for a 6-inch pipe with ¼-inch diameter perforations to protect the subgrade soil shown in chart 1. The soils represented by curves A and B, chart 1, are readily available from local borrow pits. You tabulate the following data from the chart:

Soil A	**Soil B**	**Subgrade (protected soil)**
D_{10} = 1.4 mm	D_{10} = .25 mm	
D_{15} = 2.2 mm	D_{15} = .30 mm	D_{15} = .01 mm
D_{50} = 13.5 mm	D_{50} = 1.0 mm	D_{50} = .042 mm
D_{60} = 19.0 mm	D_{60} = 2.0 mm	D_{85} = .09 mm
D_{85} = 38.0 mm	D_{85} = 13.0 mm	

The symbol D_{10}, D_{50}, etc, represents the size of that particle of a soil of which the percentage indicated by the subscript is finer by weight. For example, if D_{50} of a particular soil is 10 mm, then 50 percent of that soil by weight is smaller than 10 mm.

Check for coefficient of uniformity of both soils:

$$\frac{\text{Cu}}{\text{soil A}} = \frac{D_{60}}{D_{10}} = \frac{19.0}{1.4} = 13.57$$

$$\frac{\text{Cu}}{\text{soil B}} = \frac{D_{60}}{D_{10}} = \frac{2.0}{.25} = 8.0$$

Thus soil A and soil B both satisfy the requirement that the coefficient of uniformity of the filter material should be less than 20. Computations should then proceed in the following manner:

Soil A

$\frac{D_{15}\text{ (filter)}}{D_{85}\text{ (protected soil)}}$ Should be equal to or less than 5 to prevent movement of the subgrade soil through the filter material.

$\frac{2.2}{.09} = 24.4$ which is not less than 5

Therefore, filter material A is unsuitable because movement of the subgrade soil through the filter material is possible.

Soil B

$\frac{D_{15}\text{ (filter)}}{D_{85}\text{ (protected soil)}}$ Should be equal to or less than 5 to prevent movement of subgrade soil through the filter.

$\frac{.30}{.09} = 3.33$ which is less than 5

$\frac{D_{50}\text{ (filter)}}{D_{50}\text{ (protected soil)}}$ Should be equal to or less than 25 to prevent movement of subgrade soil through the filter.

$\frac{1.0}{.042} = 23.8$ which is less than 25

$\frac{D_{15}\text{ (filter)}}{D_{15}\text{ (protected soil)}}$ Should be equal to or greater than 5 to permit water movement through the filter.

$\frac{.30}{.01} = 30$ which is greater than 5

$\frac{D_{85}\text{ (filter)}}{\text{hole diameter}}$ Should be greater than 1.0 to prevent clogging of the pipe.

Note that the soil particle size is usually given in millimeters while the hole size is usually given in inches. The two dimensions must be expressed in compatible units before the preceding formula is used. This may best be accomplished by multiplying the size of the pipe perforations in inches by 25.4 which represents the number of millimeters in 1 inch. For the example, with Soil B under discussion:

$$\frac{D_{85}\text{ (filter)}}{\text{hole diameter}} = \frac{13.0\text{ mm}}{\frac{1}{4} \times 25.4} = \frac{13}{6.35} = 2.0 \text{ which is greater than 1.0}$$

Thus soil B satisfies all the criteria for a good filter material while soil A does not.

5-9. STEPS IN FILTER DESIGN

In any case in which it is necessary to design or select a filter material from several readily available sources, the computations would be set up in essentially the same manner, with the steps below being presented in the proper sequence:

Obtain a mechanical-analysis report of the materials locally available for use as filters.

Determine which of the materials satisfies all the criteria listed in paragraph 5-6.

The most efficient and most practical type of subdrainage system is the one which adequately performs the operations for which it was intended and in addition, was installed with the carefulness and economy consistent with its purpose. Any attempt to save costs by the use of a sketchy or inadequate subdrainage system is false economy. Conversely, any attempt to install an elaborate system of underground piping where a simple V-ditch would serve as well should likewise be discouraged.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space provided below the question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in back of this booklet. Do not send in your solutions to these review exercises.

1. What is meant by the term "coefficient of permeability" as related to soil? (5-1a)

2. Subgrade drainage must be installed when seasonal fluctuations of ground water is expected to rise to a level within what distance below the bottom of the base course? (5-1b)

3. If it is impracticable to handle a subsurface drainage problem by gravity drainage, what method may be used to relieve the drainage problem?. (5-2a)

4. Subsurface drainage is sometimes taken care of by deep V-ditches. What are two disadvantages of this method? (5-2b)

5. What kind of pipe is most commonly used in a subsurface drainage system? (5-2d(1))

6. When determining the slope of a pipe, the invert elevation is used. What is the definition of the invert of a pipe? (5-3a)

7. In a subsurface drainage pipe system what is the maximum spacing between manholes? (5-3b)

8. What is the minimum distance the center of a subgrade drainpipe should be below the ground-water table? (5-3d)

9. What method of disposing of subsurface water is often used in areas where deep freezing occurs? (5-4)

10. What is one of the most important construction features in determining the success or failure of a subsurface drainage system? (5-5)

11. Explain the three ways in which a drainage system can become inoperative as a result of the selection of improper filter material. (5-5)

12. What relationship must exist between the filter material and the protected soil to permit free water to reach the drainpipe? (5-6c)

13. What soil characteristic is indicated by a smooth grain-size curve with gradual changes of slope? (5-6e)

14. How can you identify a skip-graded soil by inspection of soil curves on a mechanical-analysis chart (5-6e)

15. When more than one layer of filter material must be used, what is the first layer to be designed? (5-7)

16. Soil particle sizes are usually given in millimeters while the hole size in drainage pipes is given in inches. What action must you take in this regard when using the filter design formulas? (5-8)

17. Referring to the mechanical analysis curves on chart 1, determine whether or not soil B will clog the drainpipe if the round holes in the pipe are ½-inch diameter. (5-6a, chart 1)

18. Referring again to chart 1, determine whether or not the coefficient of uniformity (Cu) of soil A is such that the material will not segregate during placement. (5-6d, chart 1)

19. From data given on chart 2, determine whether or not soil C will prevent the movement of particles from the protected soil (soil D) into or through the filter. (5-6b, chart 2)

20. Using data given on chart 2, determine whether or not soil B will permit free water from the protected soil (soil D) to reach the drainage pipe. (5-6c, chart 2)

ANSWERS TO REVIEW EXERCISES

LESSON 1

1. The first construction work on any project should provide drainage for the work to follow. (1-1)

2. Classification of drainage depends upon whether the water is on or below the surface of the ground at the point where it is first intercepted or collected for disposal. (1-2)

3. Ditches, alone or in combination with natural watercourses, provide the simplest as well as the cheapest and most efficient method for handling surface water. (1-3a)

4. A sanitary system collects all sewage in one system and carries it to a treatment and disposal plant. Storm sewer systems are best installed in small units, each draining a small area, and disposing of the water in the nearest natural watercourse. (1-3d)

5. Open channels, subdrains, combination drains, and vertical wells are used to control ground water. (1-4)

6. Cut and fill sections must be crowned and high shoulders must be lowered. (1-5c)

7. Gravel roads and other rough untreated surfaces require a crown of ½ to ¾ inch per foot. (1-7a)

8. Proper grading is the most important single factor contributing to the success of the drainage system. (1-8b)

9. If the road or airfield is to be used for only a short period of time, such as one or two weeks, hasty design procedures would probably be used. (1-9b)

10. Rainfall data for the locality being considered is of primary importance in designing a drainage system that will insure prompt removal of surface water and positive control of ground water. (1-10b)

11. Variations in the state of compaction, soil-moisture deficiencies at the beginning of rainfall, and the elevation of the ground-water table may greatly influence the infiltration capacity of a particular soil. (1-10c)

12. Dry and cracked earth is a sign of loss of water through evaporation and may indicate an impervious subsoil and inadequate subsurface drainage. (1-11)

13. Preliminary consideration of the type of installation required, the engineer resources available, and the amount and reliability of the data collected, determine the degree of design necessary. (1-12)

14. The design storm is that storm which may be expected to be equalled or exceeded on an average of one time during the design period. (1-13)

15. Drainage for military construction should be based on a 2-year design storm frequency, unless exceptional circumstances require greater protection. (1-13b)

16. The duration of rainfall required to produce the maximum rate of runoff will depend primarily upon the length of overland flow, taking into account surface detention, roughness factor, and other surface-runoff characteristics. (1-13d)

17. The problems relating to subsurface drainage may best be handled when construction operations on a road or airfield are initiated. (1-15)

18. The flow of water in soils containing organic and inorganic fine sands, silts, and course-grained soils containing an excess of nonplastic fines, is impeded by their characteristic density. (1-16b)

19. A "pumping" action occurs which will form a void under the pavement and failure ultimately occurs by cracking of the surface. (1-20a)

20. In this case, thawing is from the bottom up due to transference of heat from the interior of the earth, and there is little tendency for a reduction in subgrade stability to occur. (1-20b)

ANSWERS TO REVIEW EXERCISES

LESSON 2

1. Size, shape, and slope are the most important factors which affect the rate and quantity of runoff. (2-2a)

2. Sheet flow can be expected to become channelized flow in 400 feet or less. (2-21)

3. The Hasty Method for calculating the size of a drainage structure required is used only when time does not permit the use of a more exact method. (2-4b)

4. A complex area is one that is composed of two or more different soil types, cover, or man-made areas, no one of which constitutes 80% of the area. (2-6b(5)(b))

5. Expressed mathematically the value of "C" is the ratio of runoff to rainfall, or $\frac{\text{runoff}}{\text{rainfall}}$. (2-7)

6. The reason for the correction is that as the ground slope increases the rainfall runoff will flow at a faster rate, thereby reducing the time available for the water to infiltrate the soil. (2-7b(1))

7. If the drainage area consists of two or more types of soil or cover, and no one type equals or exceeds 80% of the total area, it is classified as a complex area. In a complex area, the "C" value must be weighted. (2-7c(1))

8. Before the "C" value is weighted, the "C" value assumed must be corrected for slope. (2-7c(2))

9. Maximum runoff occurs only when the rain falls over the entire area and the storm lasts for the area time of concentration (TOC). (2-8b(1))

10. Representative flow paths must be determined before you can determine an area time of concentration (TOC). (2-8c(1)(a))

11. A representative flow path is one that is representative of the time at which the majority of the area will be contributing runoff to the outlet point. (2-8c(1)(a))

12. On figure 1-5, lesson 1, find the intersection of the 2.2 curve and the 30 minute duration line. From this intersect, move horizontally left to the rainfall intensity in inches per hour line and read 3.5 inches. (figure 1-5, lesson 1)

13. Enter figure 2-4 at average turf, move left to 6% curve, follow 6% curve line down to 300 foot line, read vertical line downward, read 11 minutes TOC.

14. Enter figure 2-4 at paved area, go left to 1% curve, move up curve to 800 foot line, drop vertically down to bottom of figure, read 37 minutes TOC. (2-8c(2)(c)(2), fig 2-4)

15. The critical storm duration, for the purpose of determining that storm's intensity, is set equal to the time of concentration (TOC). (2-8d)

16. Knowing the geographical location of the drainage area, you go to the world isohyetal map (fig 2-5) where you can find the one-hour, two-year rainfall intensity for any area of the world. This value is the number of the curve you use. (2-8d(1))

17. From the world isohyetal map, the eastern tip of Brazil would have a one-hour, two-year rainfall intensity of 2 inches. (8-2d(1))

18. The one-hour, two-year rainfall intensity for Washington, DC is 1.5 inches per hour. Refer to figure 1-5, lesson 1, interpolate between the 1.4 and 1.6 curves to the 35 minute line, read 2.3 inches per hour. (8-2d(1), (2))

19. Delineation lines mark the boundary of the drainage area, thereby permitting the area to be measured. (2-9a)

20. An area on a map may be measured by use of a planimeter, by using geometric shapes, or by the stripper method. (2-9b)

ANSWERS TO REVIEW EXERCISES

LESSON 2A

1. The slope, cover, shape, and general character of the drainage area are all considered in the coefficient "C" of the formula $A = C\sqrt[4]{D^3}$. (2A-5)

2. The value of "C" should be increased as the length of the valleys decrease in proportion to their widths. (2A-5)

3. From table 2A-1 read 5.1 square feet. (table 2A-1)

4. From figure 2A-1 read 48 inches. (fig. 2A-1)

5. Pipe diameter (ft) $= \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 7}{\pi}}\sqrt{8.9} = 2.98$ ft = 35.8″. Use 36″ diam. (2A-5)

6. These curves may be used for different values of "n" and "S" by determining and using an equivalent length (L_E) instead of the measured length. (2A-6c)

7. For a complex area, the length to be used must be the weighted equivalent length. (2A-6d)

8. Determine the L_E for each type of flow from figure 2A-2, using the coefficient of retardation, average length, and average slope for each type of flow. Add them all together to get the total area equivalent length. (2A-7l(1))

9. The determination for a value for "T" to be used, within the range of values given, is based upon engineering judgment. (2A-7k(3))

10. First determine the rainfall (R) for the area in a one-hour storm of two-year frequency from the isohyetal map. Next determine the infiltration rate (I) as illustrated in paragraph 2A-7k. Then, supply rate (σ) = R – I. Choose the supply curve closest to the area supply rate.

ANSWERS TO REVIEW EXERCISES

LESSON 3

1. All drainage structures must be large enough to carry away the maxium design discharge. (3-2)

2. The size and gradient of pipes and well-maintained channels required to discharge design storm runoff may be determined by Manning's formula. (3-2)

3. $Q = A \frac{1.486}{n} R^{2/3} S^{1/2}$ **(3-2a)**

4. Wetted perimeter is the linear measurement of that portion of the perimeter of the ditch or structure actually wetted by the flow. (3-2b)

5. $wp = 2\sqrt{\left(\frac{ad}{h}\right)^2 + d^2} + b$ **(3-2b(2))**

6. .022 (3-2c) (Annex A-2, 7b)

7. The hydraulic radius is determined by dividing the cross-sectional area of the flow by the wetted perimeter. (3-2e)

8. $R = \frac{\frac{12 \times 2}{2}}{2\sqrt{6^2 + 2^2}} = \frac{12}{2\sqrt{40}} = \frac{12}{2 \times 6.32} = 0.95$ **ft. (3-2e)**

9. $wp = \pi d = 3.1416 \times 3 = 9.43$

$\text{area} = \frac{\pi d^2}{4} = \frac{3.1416 \times 9}{4} = 7.08$

$R = \frac{7.08}{9.43} = 0.75$ **ft. (3-2b(3)) (3-2e)**

10. $A = 3d^2$

$wp = 2\sqrt{9d^2 + d^2} = 6.32d$

$R = \frac{A}{wp} = \frac{3d^2}{6.32d} = 0.475d$

$Q = A \frac{1.486}{n} R^{2/3} S^{1/2}$ **(see exercise 3)**

$$16 = 3d^2 \left(\frac{1.486}{0.02}\right) (0.475d)^{2/3} \ (0.01)^{1/2}$$

$$16 = 3d^2 \ (74.3) \ (0.475)^{2/3} \ d^{2/3}(0.01)^{1/2}$$

$$16 = 3d^{8/3} \ (74.3) \ (0.609) \ (0.10)$$

$$d^{8/3} = \frac{16}{3(74.3) \ (0.609) \ (0.10)} = 1.18$$

$$d = (1.18)^{3/8} = 1.063, \text{ or } 1.0 \text{ ft. } (3\text{-}3a)$$

11. $V = \frac{Q}{A} = \frac{16}{3 \times 1} = 5.3$ ft/sec. (3-3a)

12. Assume d = 1.5 ft

$$Q = (9 \times 1.5 + 1.5^2) \ (49.53) \left(\frac{13.5 + 3.38}{5.4 + 9}\right) (0.0775)$$

$$= 16.88 \times 49.53 \times 1.17 \times 0.0775$$

$$= 75.5 \text{ cfs. } \therefore 1.5 \text{ ft is depth of flow } (3\text{-}3b)$$

13. The ditch capacity required and the capabilities of the equipment available. (3-4a)

14. A 6-inch freeboard is normally allowed. (3-4a)

15. The minimum ditch base width is 10 feet because that is the working width of the scraper. (3-4b)

16. You must know the type of pipe to be used, the size, and the slope it is to be laid on. (3-5)

17. 0.6 percent slope. (3-6) (annex A-4)

18. 40 cfs. (3-6) (annex A-4)

19. 2.0 percent. (3-7) (annex A-4)

20. At the critical slope. (3-7)

21. 5 fps. (3-8) (annex A-4)

22. 3.5 ft/sec. (3-8) (annex A-3)

ANSWERS TO REVIEW EXERCISES

LESSON 4

1. If water will accumulate in the trench during construction, the trench must be excavated uphill to avoid working in water. (4-1)

2. A minimum grade of 0.5 percent should be maintained to prevent water from standing in ditches. (4-2)

3. Erosion may occur at any point where the force of moving water exceeds the cohesive force of the material with which the water is in contact. (4-3)

4. Checkdams are not used when the grade exceeds 5 percent because this would require placing the dams too close together. (4-4)

5. Minimum length of apron for a drop of 3 feet is 9 feet ($3 \times 3 = 9$). (4-4a)

6. $$S = \frac{100 \times H}{A - B} = \frac{100 \times 2}{4 - 2} = \frac{200}{2}$$
$$= 100 \text{ ft spacing.}$$ (4-4a)

7. The weir notch slot is always constructed ½ foot deeper than the depth of flow as a safety factor. (4-4b)

8. $$Q = CLH^{3/2}$$
$$8 = 3 \times 2.5 \times H^{3/2}$$
$$H^{3/2} = \frac{8}{3 \times 2.5} = 1.067$$
$$H = \sqrt[3]{1.067^2} = 1.04$$ depth of water (4-4b)

9. The capacity of a specific grate depends upon the depth of water over the grate head. (4-5)

10. Read from table 4-2, right from 24" x 24" to column under 1.4 ft. Capacity is 12.7 cfs (4-5, table 4-2)

11. A ditch-relief culvert under such conditions should be placed at a 60 degree angle to the road centerline. (4-6a)

12. If the outlet end of a culvert is below the surface of a stream the culvert may fill with sediment. (4-6b)

13. If the slope is varied, the steepest slope should be at the outlet end. (4-6c)

14. The minimum distance between pipes in a multiple-pipe culvert should be one-half the diameter of the pipe. (4-6d)

15. The foundation is convexed upward along the centerline to allow for future settlement and to insure tightness in the lower half of the joints. (4-6e)

16. The backfill is tamped mechanically or by hand to at least 12 inches above the culvert. (4-6f)

17. Corrugated metal pipe culvert used in roads must have a minimum of 18 inches of cover, or one-half the diameter of the pipe, whichever is larger. (4-6g)

18. For a cut section, the length of culvert required is normally found by measuring the distance from the bottom of the ditch on the upstream side to the bottom of the ditch on the downstream side. (4-7a)

19. For a culvert over 30 feet long, pipes should be a minimum of 15 inches in diameter. (4-7a)

20. The culvert must be able to carry the weight of the fill above it plus the weight of live loads that may pass over the road. (4-7b)

21. Large corrugated metal pipes are strutted before backfilling so that the final shape of the culvert will be circular instead of somewhat flattened. (4-8)

22. Culverts 60″ to 72″ in diameter should be elongated 2″ along the vertical axis dimension. (4-8a, fig 4-13)

23. Strut spacing would be 6 feet for a 60″ culvert under 25 feet of fill. (4-8b, table 4-3)

24. Headwalls and wingwalls are constructed to prevent or control erosion, guide water into the culvert, reduce seepage, and hold the ends of the culvert in place. (4-9)

25. As a general rule, drainage systems on military installations are designed to take care of the runoff from the design storm without ponding. Ponding is provided for a storm worse than the design storm. (4-10)

26. $$V = \frac{(A + B)}{2} \times b$$

$$= \frac{10{,}000 + 50{,}000}{2} \times 5$$

$$= 30{,}000 \times 5 = 150{,}000 \text{ cu ft}$$ (4-13a, b)

27. Data such as shown in table 4-4 must be tabulated before you can plot a cumulative runoff curve. (4-14b)

28. A cumulative runoff curve is used to determine the amount of water an area will contribute to a pond. (4-14)

29. At the point of intersection of these two lines, the volume of water accumulated and the volume of water discharged are equal, so there is no ponding condition existing. (4-15b)

30. Determine the point where the two lines are separated the greatest vertical distance. This point represents the greatest difference between the volume of water accumulated and the volume discharged. (4-15c)

31. Ponding will appreciably reduce pipe sizes for areas that have a short time of concentration. (4-16)

32. Corrugated metal pipe (CMP) is the most common pipe material used for culverts in the theater of operations. (4-17a)

33. Where ponding is undesirable, culverts should have sufficient capacity to pass the peak runoff from the design storm without allowing the water surface at the inlet to become higher than the inlet. (4-18a)

34. The "head" on a culvert where the inlet is submerged and the outlet not submerged is the difference in elevation of the water surface directly above the inlet and the top of the outlet. (4-18b)

35. The "critical slope" for a culvert is the minimum slope of the hydraulic gradient that will permit maximum discharge. (4-18c)

ANSWERS TO REVIEW EXERCISES

LESSON 5

1. The coefficient of permeability is a property of the soil and is defined as the discharge velocity at a unit hydraulic gradient. (5-1a)

2. When seasonal fluctuations of ground water may be expected to rise to a level less than 1 foot below the bottom of the base course, subgrade drainage is required. (5-1b)

3. If a gravity drainage system is impracticable, it may be feasible to solve the problem by increasing the depth of the base course so that the water table is a specified distance below the top of the base course. (5-2a)

4. Deep V-ditches may create traffic hazards and they are subject to erosion. (5-2b)

5. The most common form of subsurface piping is perforated pipe. (5-2d(1))

6. The invert is defined as the lowest point in the internal cross section of the pipe at one particular location. (5-3a)

7. Manholes should be provided at intervals of not more than 1,000 feet. (5-3b)

8. Center of subgrade lines should be not less than 1 foot below the ground-water table. (5-3d)

9. Vertical wells are constructed to permit trapped subsurface water to pass through an impervious soil or rock layer to a lower, freely draining layer of soil. (5-4)

10. The selection of the proper filter material is of great importance since it determines to a larger extent the success or failure of the drainage system. (5-5)

11. If improper filter material is used, a drainage system may become inoperative in any of the following three ways: (5-5)

   a. The pipe may become clogged by the infiltration of small soil particles.

   b. Particles in the protected soil may move into or through the filters, causing instability of the surface.

   c. Free ground water may not be able to reach the pipe.

12. To permit free water to reach the pipe, the filter material must be many times more pervious than the protected soil. (5-6c)

13. Well-graded soils generally have a smooth grain-size curve with gradual changes of slope. (5-6e)

14. The soil curve for a skip-graded soil is horizontal through the range of missing sizes, giving the curve the appearance of a hump in that area. (5-6e)

15. When more than one layer of filter material is required, the designer should select the filter material to be placed around the pipe first. (5-7)

16. The hole size must be converted from inches to millimeters by multiplying the inch size by the factor 25.4. (5-8)

17. $$\frac{\text{85-percent size of filter material}}{\text{hole diameter}}, \text{ is greater than 1.0}$$

$$\frac{13}{\frac{1}{2} \times 25.4} = \frac{13}{12.7}, \text{ is greater than 1.0}$$

∴ soil B will not clog the drain pipe. (5-6a, chart 1)

18. $$\text{Cu} = \frac{\text{60-percent size of filter material}}{\text{10-percent size of filter material}}, \text{ is less than 20}$$

$$= \frac{19}{1.4} = 13.6,$$ ∴ segregation will not occur (5.6d, chart 1)

19. Two conditions must be satisfied:

$$\frac{\text{15-percent size of filter material}}{\text{85-percent size of protected soil}}, \text{ is less than or equal to 5}$$

and, $$\frac{\text{50-percent size of filter material}}{\text{50-percent size of protected soil}}, \text{ is less than or equal to 25}$$

$$\frac{0.80}{0.27} = 2.96 \text{ is less than 5}$$

$$\frac{5.20}{0.115} = 45.2 \text{ is greater than 25}$$

∴ soil C is not acceptable. (5-6b, chart 2)

20. $$\frac{\text{15-percent size of filter material}}{\text{15-percent size of protected soil}}, \text{ is greater than or equal to 5}$$

$$\frac{0.46}{0.017} = 27.0, \text{ is greater than 5}$$

∴ free water will reach the pipe. (5-6c, table 2)

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EXAMINATION

ARMY CORRESPONDENCE COURSE • ENGINEER SUBCOURSE 359-3

DRAINAGE

CREDIT HOURS ______________________3
TEXT ASSIGNMENT __________________Review previous lessons.
MATERIALS REQUIRED _______________Annex A.
Chart 3.

EXERCISES

First requirement. Solve multiple-choice exercises 1 through 10 which will test your knowledge of basic drainage principles.

1. All drainage can be classified as surface or subsurface. Which of the following provides the simplest, cheapest, and most efficient method for handling surface water?

a. embankments
b. ditches
c. storm drains
d. culverts

2. In what way, in regard to installation, do culverts differ from storm drains?

a. generally conform to the grade and alinement of the natural drainage channel
b. provide for the disposal of both surface and subsurface water
c. drain a small area and carry the water to the nearest watercourse
d. are only used where the construction is to be of a permanent nature

3. When a subdrain is so constructed that it will permit the entrance of surface water, what is it called?

a. open subdrain
b. intercept subdrain
c. French drain
d. combination drain

4. Your unit is responsible for construction of the taxiway shown in figure E-1. Clearing and grading operations have just started and many large trees must be removed. What is the first action you should consider in regard to the drainage problem?

a. construct a culvert at the intersection of the natural drainage channel and taxiway
b. attempt to drain the swampy area with outfall and/or diversion ditches
c. construct side ditches along both shoulders of the taxiway as in final plans
d. relocate the natural channel

5. Construction operations on a road are being suspended for 3 days. Near the end of the last shift of the day that work is to be suspended, you observe that the cross section of a partially completed length of road is as shown in figure E-2. What action, if any, would

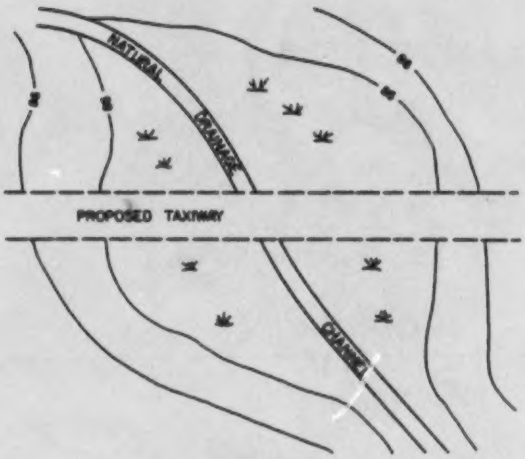


Figure E-1. For use with exercise 4.

you direct before suspending the project?

a. install open-top culverts

b. install diversion ditches

c. crown the subgrade

d. no action required

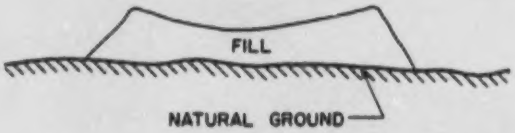


Figure E-2. For use with exercise 5.

6. Erosion of the traveled way parallel to the road centerline, as shown in figure E-3, has occurred. The road is gravel surfaced and has a steep grade. Which of the following courses of action is most appropriate for handling this drainage problem?

a. construct open-top culverts

b. install perforated pipe

c. improve side ditches

d. no action required

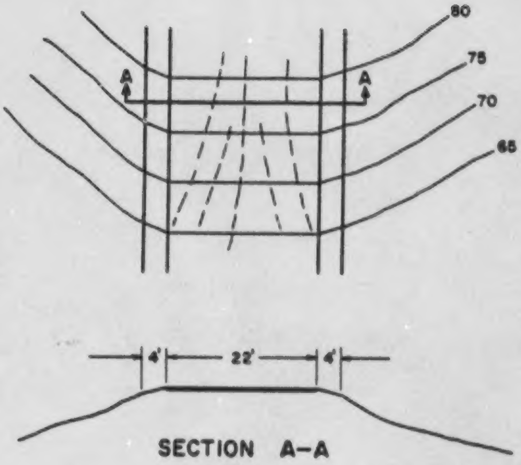


Figure E-3. For use with exercise 6.

7. Unless exceptional circumstances require greater protection, drainage for military construction should be based upon what design storm frequency, in years?

a. 1

b. 2

c. 5

d. 10

8. In road and airfield construction, what is the best time to take care of the problems relating to subsurface drainage?

a. prior to establishing final plans

b. before other construction work starts

c. when construction operations are initiated

d. upon completion of other construction

9. What is the most likely cause of pavement failure if the subsoil under the pavement varies abruptly from clean sand to silty sand mixtures, the water table is 3½ to 4 feet below the roadway surface, and the area has extended freezing periods?

a. differential frost heaving

b. settlement of subgrade

c. failure by pumping

d. uniform frost heaving

10. From the standpoint of maintenance of roads and airfields it is desirable that thawing seasons approach slowly, with temperatures remaining just above freezing for some time. Why is this?

a. the longer the ground remains frozen the less maintenance that is required

b. a slow thaw from the top down provides more time for water to run off

c. this allows thawing from the bottom up and the released water can escape downward

d. it increases surface water rather than subsurface water and reduces drainage problems

Second requirement. Solve multiple-choice exercises 11 through 20 which will test your knowledge of surface runoff.

11. By the Hasty Method, how many 36-inch-diameter pipe culverts will be needed for a stream having a bed width of 5.0 feet, a depth of water at high-water mark of 2.0 feet, and a width of stream at high-water mark of 7.0 feet?

a. 1 c. 3

b. 2 d. 4

12. For an area to be classified as a complex drainage area which of the following conditions must exist?

a. area must have some flat and some rolling terrain with varieties of cover

b. may have any number of types of soil or cover but one must equal 80% of the area

c. must include successive drainage areas requiring determination of equivalent lengths

d. must have two or more types of soil or cover, none equal to or exceeding 80% of the area

13. In the Rational Method the factor "C" is the ratio of runoff to rainfall. Why is "C" always adjusted when ground slopes exceed 2%?

a. greater slopes result in reduced ratio of runoff to rainfall

b. "C" must be increased to reflect the greater amount of water loss

c. as slopes increase runoff flows faster and there is less infiltration

d. at 2% slope sheet flow becomes channelized and evaporation is reduced

14. Maximum runoff from a drainage area will occur only if the rainstorm had two particular characteristics. Which of the following includes these two characteristics?

a. must cover the entire area for a period just equal to the time of concentration

b. should be heaviest in the area around the outlet

c. must continue at its maximum intensity beyond the TOC

d. must continue beyond the TOC but its intensity may lessen

15. You have determined that the TOC for a drainage area in the vicinity of New Orleans, Louisiana to be 35 minutes. What rainfall intensity will you expect for the TOC?

a. 3.0 c. 4.0

b. 3.5 d. 4.5

16. In order to apply the formula Q = CIA it is necessary to know the size of the drainage area in acres. What must be done before the size of the area can be determined?

a. the coefficient of runoff must be selected

b. the area must be defined

c. flow paths must be located

d. outlet elevation must be established

17. What diameter round pipe, in inches, will be required for a drainage area of 40 acres in relatively flat terrain (use C = 0.3)? Solve, using nomograph for solution of Talbot's formula, fig 2A-1.

a. 18
b. 24
c. 30
d. 36

18. In working with the Corps of Engineers method for estimating runoff, why is it necessary to convert the average length of runoff flow to an equivalent length?

a. to reduce the three flow types, sheet, channelized, and ditch, to common values

b. equivalent length is used because of the irregularity in shape of most drainage areas

c. this conversion takes into account all the variables and eliminates judgment decisions

d. because the graphs used assume n = 0.40 and S = 1.0, variations must be adjusted to these values

19. Assuming that a drainage area of 10.3 acres has a weighted equivalent length of 500 feet and a weighted supply rate of 2.0 inches per hour, what would be the maximum rate of runoff in cubic feet per second?

a. 8.5
b. 12.7
c. 16.1
d. 20.6

20. The representative drainage path for a simple drainage area has sparse grass cover, is 400 feet long and is on a 2.0 percent slope. What is the equivalent length in feet for this drainage path?

a. 130
b. 141
c. 152
d. 163

Third requirement. Solve multiple-choice exercises 21 through 30 which will test your knowledge of the design of ditches and culverts.

21. A V-ditch with 5 to 1 side slopes and a flow depth of 2.0 feet is in your drainage system. What is the cross-sectional area, in square feet, of water flowing in the ditch?

a. 12.5
b. 15.0
c. 17.5
d. 20.0

22. A trapezoidal ditch has a base width of 12 feet, side slopes of 5 to 1 and a flow depth of 1 foot. What is the wetted perimeter, in feet?

a. 22
b. 26
c. 30
d. 34

23. A trapezoidal ditch 1 foot deep is covered with a good stand of grass which is 8 inches high. What value of Manning's "n" would you use in your calculations?

a. 0.020
b. 0.025
c. 0.040
d. 0.045

24. A trapezoidal ditch has a base width of 10 feet, side slopes of 4 to 1, and a flow depth of 3 feet. What is the hydraulic radius in feet?

a. 0.9
b. 1.4
c. 1.9
d. 2.4

25. You are determining the slope of a clear, unlined drainage ditch for an airfield. What is the minimum slope, in percent, you should consider?

a. 0.1 c. 0.5
b. 0.3 d. 0.7

26. You have established that a trapezoidal ditch 10 feet wide with side slopes of 8 to 1 and a flow depth of 1 foot will be required to carry away water collected from a runway. This ditch has an area of flow of 18 square feet, a wetted perimeter of 26.1 feet, and an n value of 0.020. What slope, in percent, will be required for a flow of 104 cfs?

a. 0.4 c. 0.8
b. 0.6 d. 1.0

27. Assuming you have a V-ditch with side slopes of 10 to 1, have calculated a runoff of 20 cfs and a flow depth of 2.0 feet, what will be the velocity of flow in the ditch, in feet per second?

a. 0.25 c. 0.75
b. 0.50 d. 1.00

28. A trapezoidal ditch has a slope of 1 percent, a width of 10 feet at the bottom, side slopes of 12 to 1, an n value of 0.025, and the depth of flow is observed to be 1 foot. What is the rate of flow in cfs in this ditch?

a. 78 c. 98
b. 88 d. 108

29. What size concrete pipe, diameter in inches, will be required for a culvert which will be placed on a 0.6 percent slope and must carry 73 cfs?

a. 36 c. 48
b. 42 d. 60

30. What is the velocity of flow, in ft/sec, in a 36-inch CMP installed on a 0.64 percent slope, when it is discharging 30 cfs?

a. 3.0 c. 5.0
b. 4.0 d. 6.0

Fourth requirement. Solve multiple-choice exercises 31 through 40 which will test your knowledge of drainage construction, checkdams, drop inlets, culverts, and ponding.

31. V-ditches are probably more easily constructed and maintained than trapezoidal ditches where the required capacity does not exceed a certain quantity. What is this limiting quantity, in cfs?

a. 70 c. 90
b. 80 d. 100

32. A ditch is 2,000 feet long and has a slope of 4 percent. You are to reduce the slope to 1 percent by use of checkdams. The height of drop of each checkdam is to be 2 feet. What is the spacing, in feet, of the checkdams?

a. 35 c. 67
b. 53 d. 80

33. You are designing a drainage system for a paved area and plan to use 36-inch by 36-inch-square grate inlets. For design purposes what quantity of flow, in cfs, should you consider each grate capable of discharging if the head is to be 1.0 foot?

a. 16.5 c. 37.0
b. 24.7 d. 49.4

34. You are supervising the placement of a 48-inch CMP that will run under a finished road. At what minimum depth, in inches, below the finished road surface should you place the bottom of the CMP?

a. 54 c. 66
b. 60 d. 72

35. You are to determine the maximum diameter culvert that can be placed under the taxiway in figure E-4 and that will satisfy cover requirements. The only pipe available is 10-gage CMP and the design load is a 120,000-pound plane. What is the maximum diameter, in inches, that you should specify for this particular culvert?

a. 24

b. 36

c. 48

d. 60

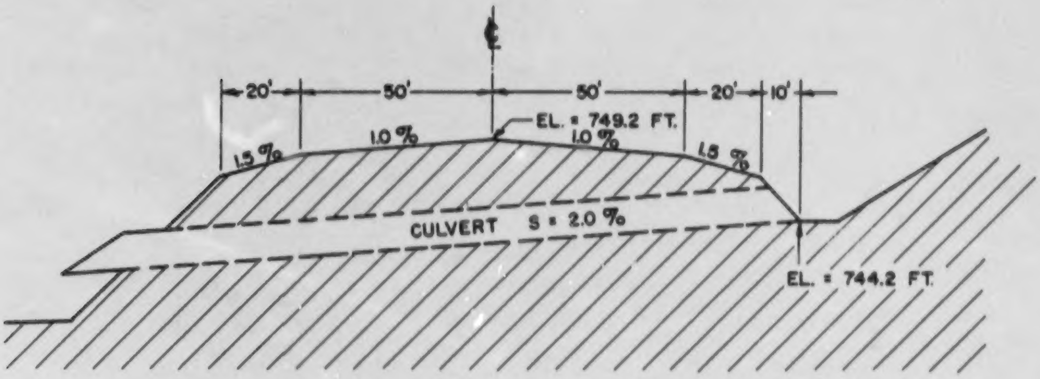


Figure E-4. For use with exercise 35.

36. You are to place a 72-inch diameter CMP culvert 175 feet long in a fill as shown in figure E-5. The ends of the CMP are not to be cut to the slope. How many linear feet of 4-inch by 4-inch timber will you need to strut this culvert? Disregard the jack struts and the bearing blocks and compression caps used with jack struts. Use nominal size of the timber (4-inch by 4-inch).

a. 647

b. 672

c. 706

d. 741

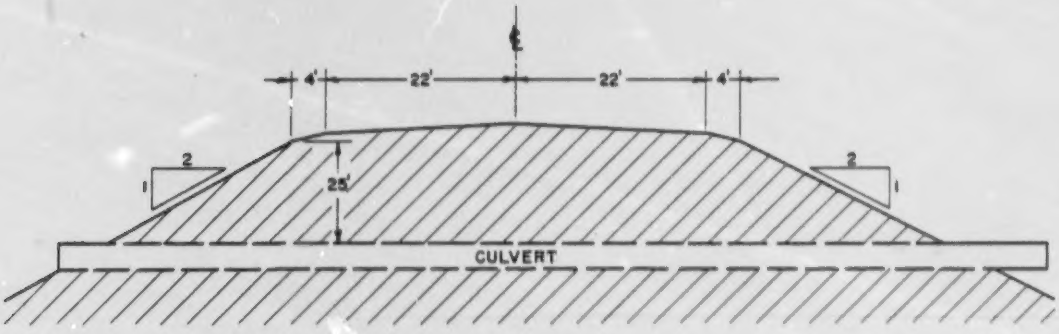


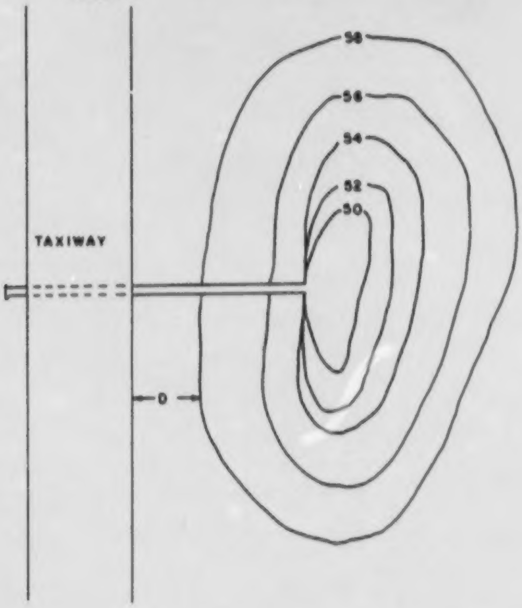
Figure E-5. For use with exercise 36.

37. It has been determined that two 48-inch diameter CMP culverts will be required. In designing a concrete headwall for these two culverts what center-to-center spacing do you provide, in feet?

a. 2 c. 6

b. 4 d. 8

38. Figure E-6 illustrates an area which is being considered for ponding. The area included within each contour line is as indicated. What will be the storage capacity, in cubic feet, if the pond is to extend to the 56-foot contour?



Area bounded by*	Total area in sq ft
58-foot contour	160,000
56-foot contour	110,000
54-foot contour	50,000
52-foot contour	18,000
50-foot contour	6,000
49-foot contour	0

*All contours are concentric.

Figure E-6. For use with exercise 38.

a. 228,000 c. 289,000

b. 255,000 d. 305,000

39. The head (H) on a culvert in which the inlet is submerged and the outlet is unsubmerged, is defined as the difference in elevation between

a. the water surface directly above the inlet and the water surface at the outlet

b. the water surface directly above the inlet and the top of the outlet

c. the invert of the culvert at both the inlet and outlet

d. the water surface above the inlet and the invert at the outlet

40. Why is it important to be able to determine the critical slope of a culvert?

a. the critical slope indicates the point where the culvert may fail

b. the capacity of the culvert is less when the critical slope is exceeded

c. at the critical slope the culvert has reached its maximum capacity

d. the velocity of flow then exceeds maximum permissible discharge velocity

Fifth requirement. Solve multiple-choice exercises 41 through 50 which will test your knowledge of subsurface drainage.

41. Line A, B, C in figure E-7 represents the profile of the centerline of a portion of a road. Road crown and the topography of the surrounding area make it extremely unlikely that inundation will occur in this portion. Tests indicate that the subgrade coefficient of permeability is about 1×10^{-4}. You determine that base drainage is necessary at which of the following?

a. A, B, and C

b. A and B only

c. A only

d. B only

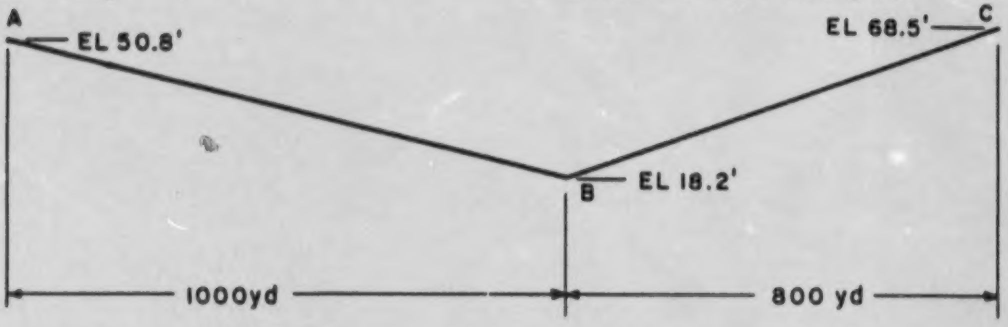


Figure E-7. For use with exercise 41.

42. A road must be constructed across a swamp at its narrowest point (about 150 feet). The ground water level is at the surface and the soil is impervious. Which of the following methods do you choose to handle this drainage problem?

a. construct french drains along shoulders of road

b. raise the road with fill at least 5 feet about ground water level

d. drain the swamp by use of trapezoidal ditches

d. install a perforated pipe collection and drainage system

43. A subdrain is required to lower the water table in the subgrade of a road. Specifications require that the invert of the 8-inch drain pipe be not less than 4 feet below the road shoulder. The drain pipe will discharge into a 48-inch culvert which normally flows half full. You are presented a plan as illustrated in figure E-8. Based upon criteria given in this subcourse, what change, or changes, if any, must you make?

a. bring the drain into the top of the culvert with a vertical pipe connection

b. increase the grade of the subdrain by lowering the outlet into the culvert

c. decrease the grade of the subdrain by lowering the pipe at point A

d. approve the plan as presented without any change

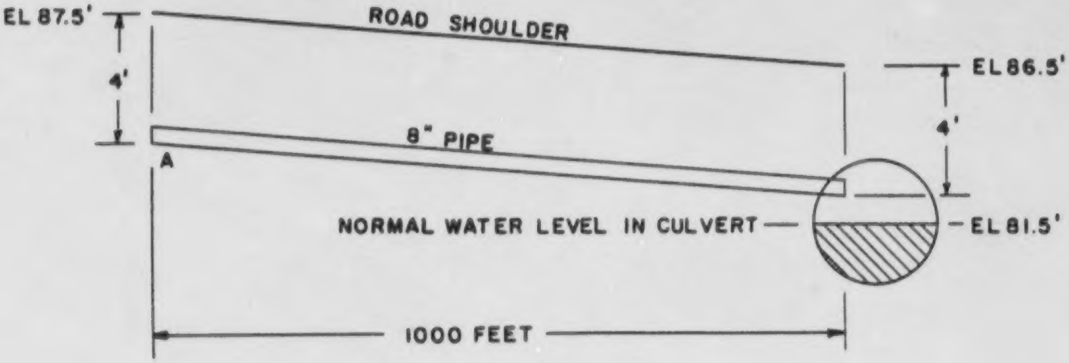


Figure E-8. For use with exercise 43.

44. A 5,000 foot runway has a subgrade drainage system consisting of a single line of 6-inch perforated pipe along each side of the pavement. Each line is 6,000 feet long, has dead ends, and discharges into 8-inch collector lines at 1,000-foot intervals. How many manholes should be installed for these drain lines?

a. 10 c. 14

b. 12 d. 16

45. You are planning to place an intercepting drain at point "A" in figure E-9. What is the minimum distance, in feet, below point A that you should place the bottom of the 6-inch open-joint drain pipe you plan to use?

a. 2.0 c. 4.5

b. 3.0 d. 5.5

Special situation. It has been decided that subsurface drainage will be required along a portion of the runway at an Army airfield. Chart 3 shows mechanical analysis of the subgrade soil and of the available soils, A, B, C, and D, for use as filter material. Solve exercises 46 through 50 based upon this situation. Use 25.4 millimeters per inch where conversion is required.

46. If you have pipe with 0.5-inch-wide slots, how many filter materials would be satisfactory, assuming that all the filter materials satisfy other criteria?

a. one c. three

b. two d. four

47. Pipe available for use in the subsurface drainage system has ¾-inch-diameter perforations. How many

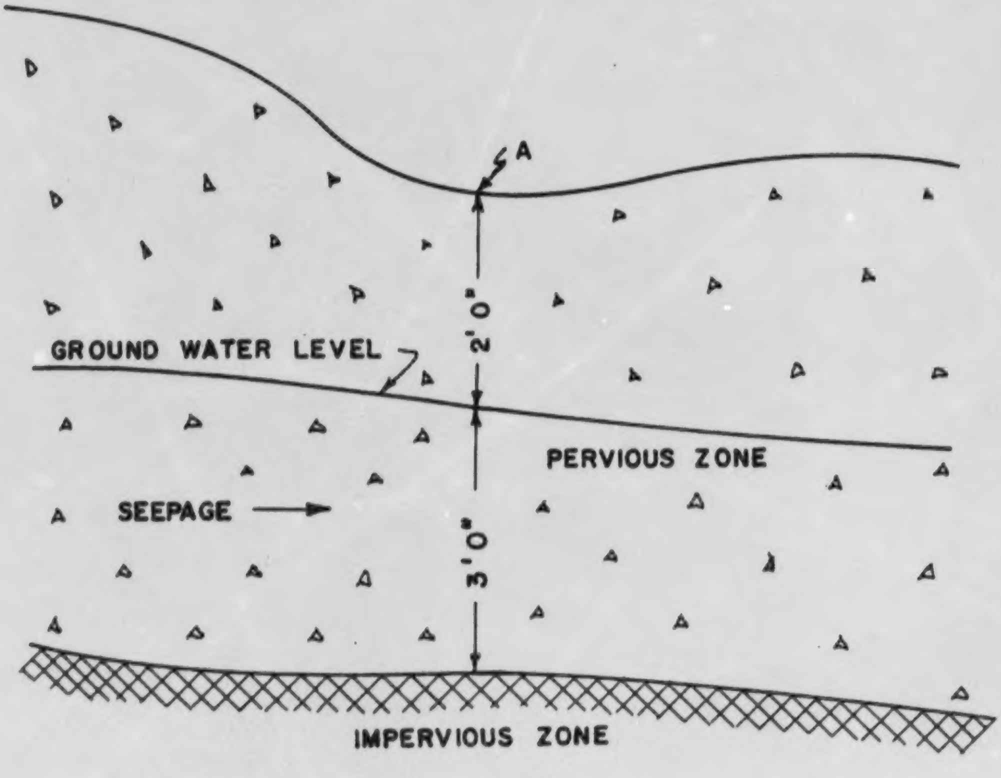


Figure E-9. For use with exercise 45.

of the filter materials shown in chart 3 may be satisfactorily used with this pipe, assuming that all of them satisfy other criteria?

a. one
c. three
b. two
d. four

48. How many of the filter materials will prevent movement of particles of the subgrade soil into or through the filter material?

a. none
c. two
b. one
d. three

49. How many of the filter materials will allow free water to pass from the subgrade soil to the pipe?

a. one
c. three
b. two
d. four

50. How many of the filter soils available for use as a filter material have a satisfactory coefficient of uniformity?

a. one
c. three
b. two
d. four

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ANNEXES A-1 THROUGH A-6

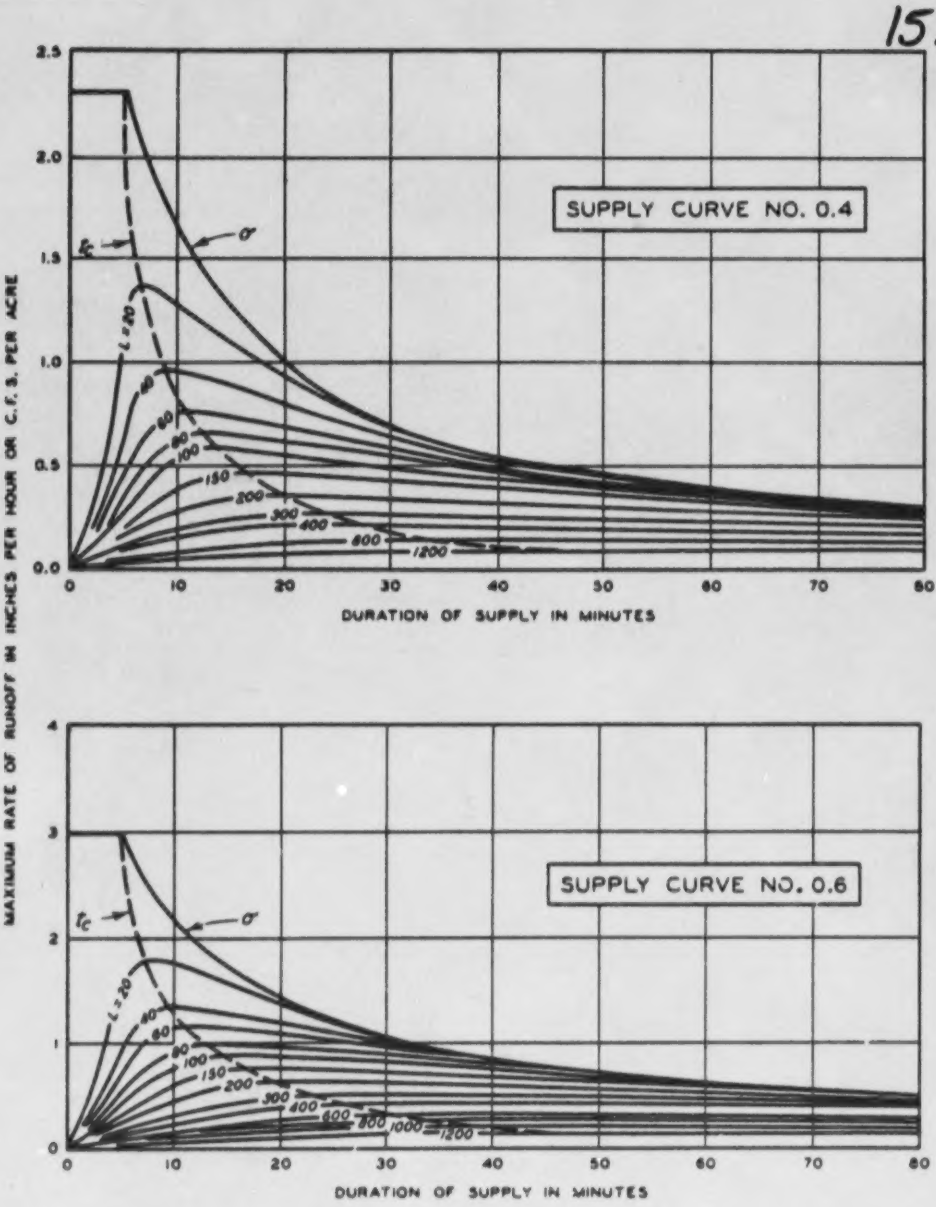
GRAPHS, CHARTS, AND TABLES

For Use With

SUBCOURSE 359

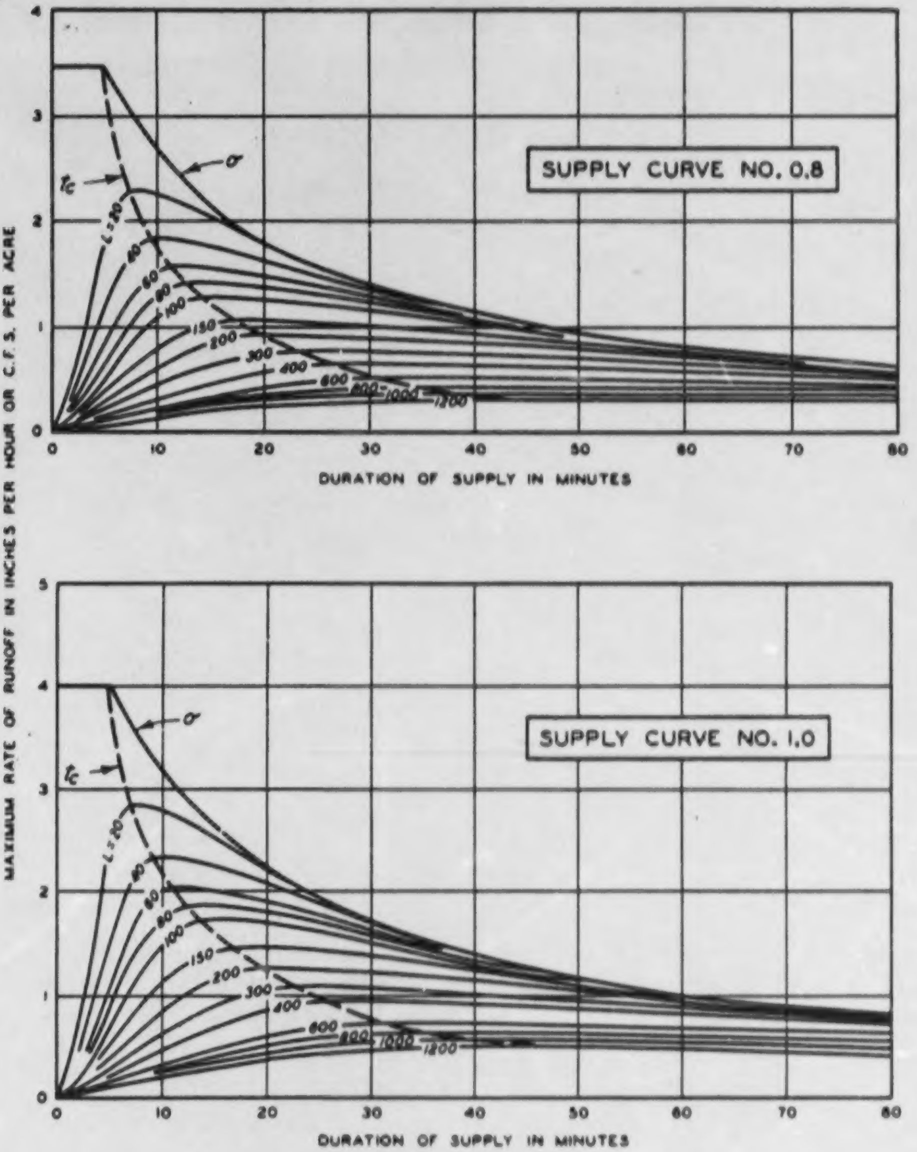
DRAINAGE

3-5



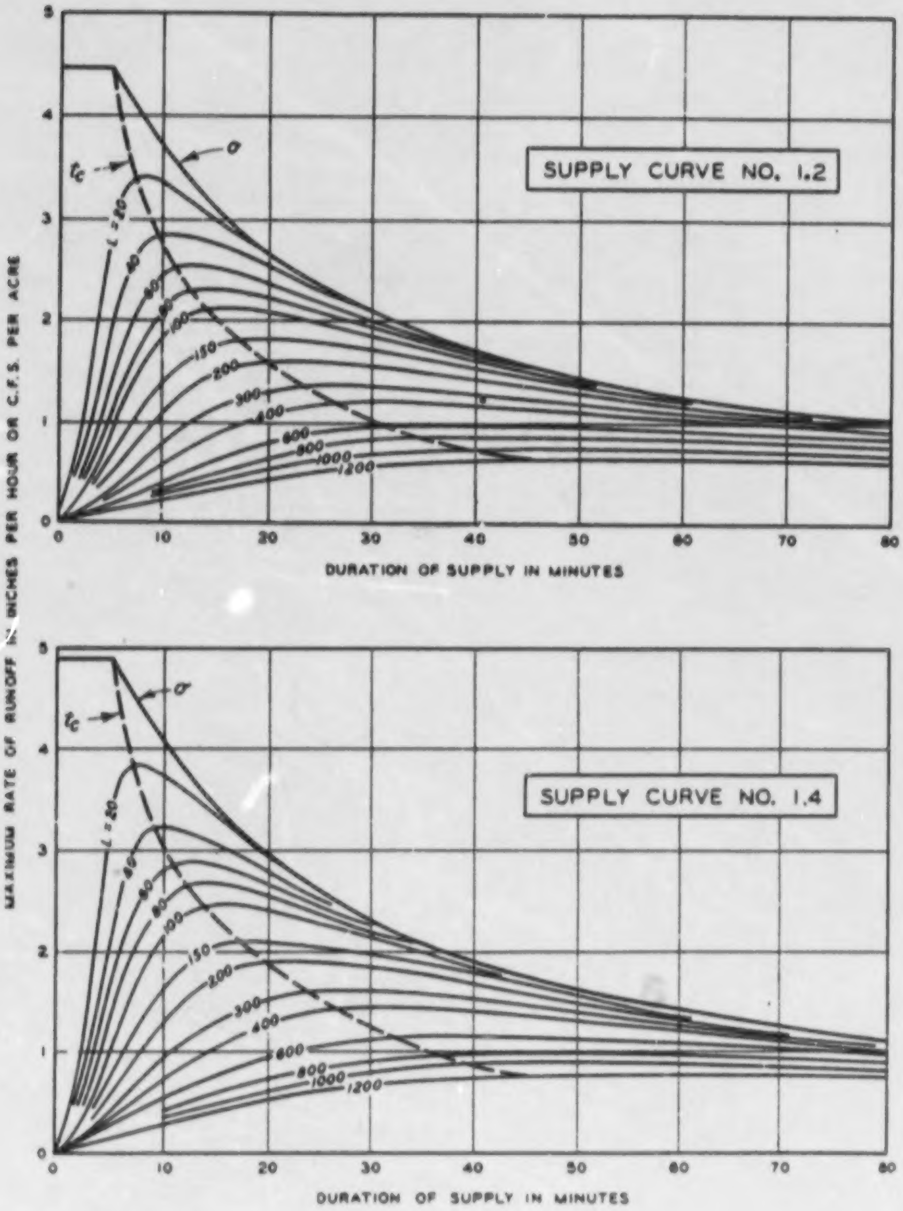
RATE OF RUNOFF CURVES

ANNEX A-1 For Use With Subcourse 359



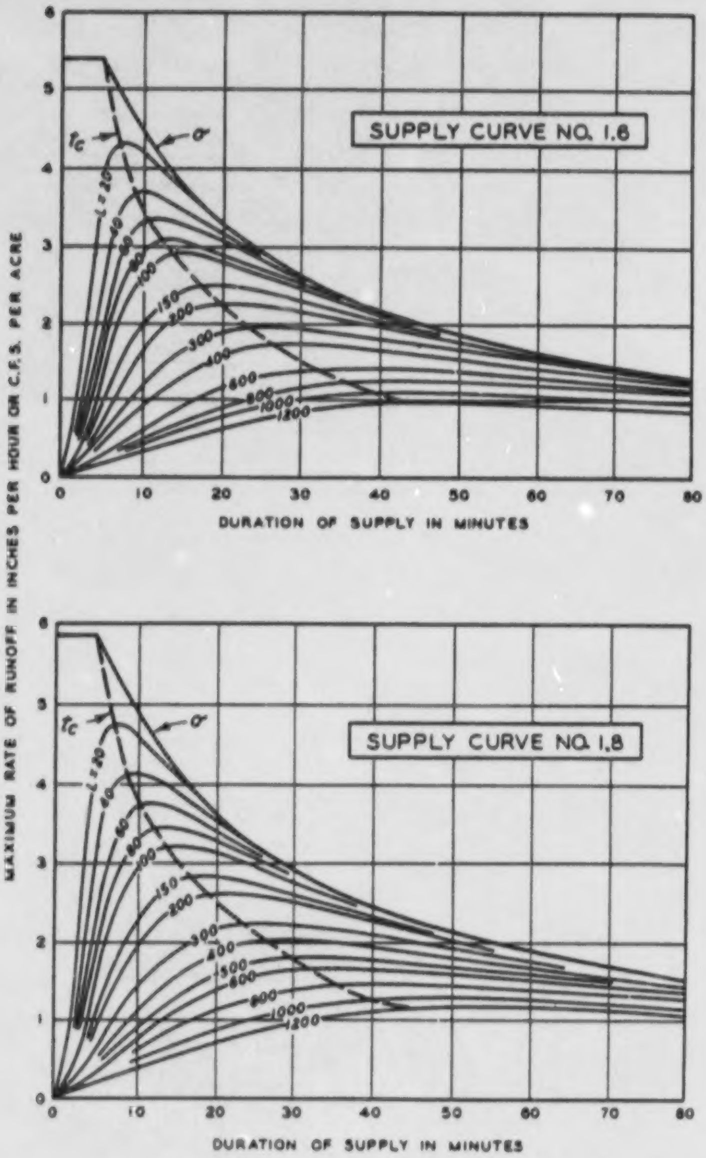
RATE OF RUNOFF CURVES

ANNEX A-1 For Use With Subcourse 359



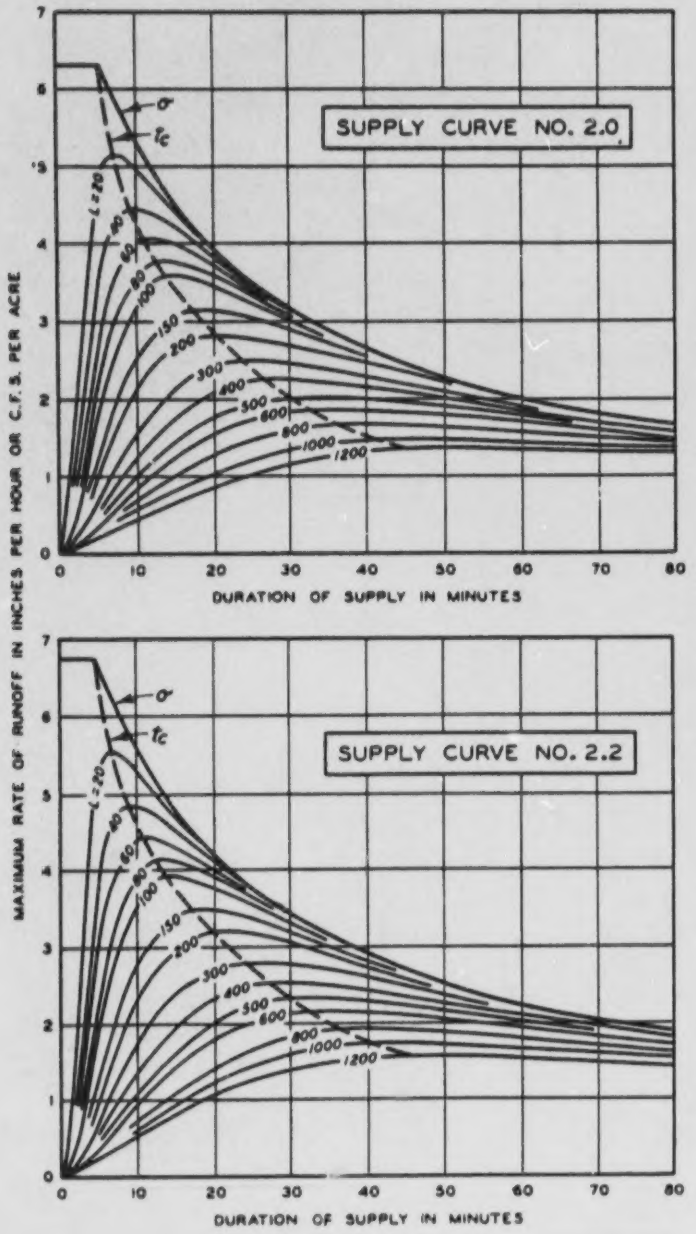
RATE OF RUNOFF CURVES

ANNEX A-1 For Use With Subcourse 359



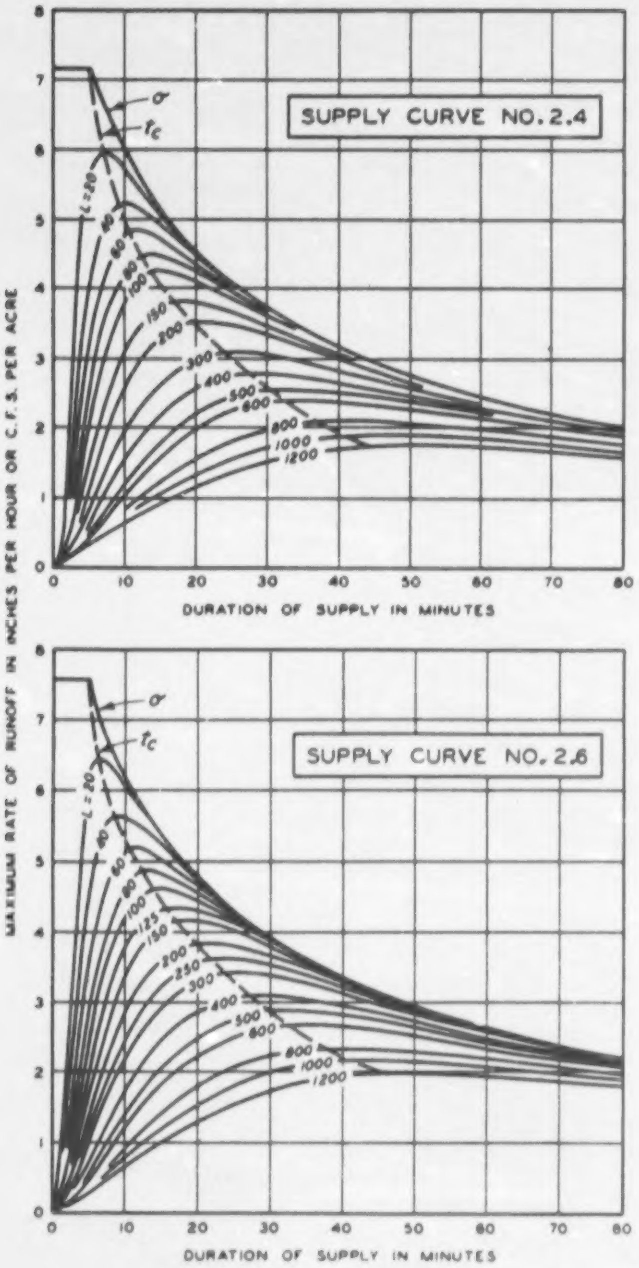
RATE OF RUNOFF CURVES

ANNEX A-1 For Use With Subcourse 359

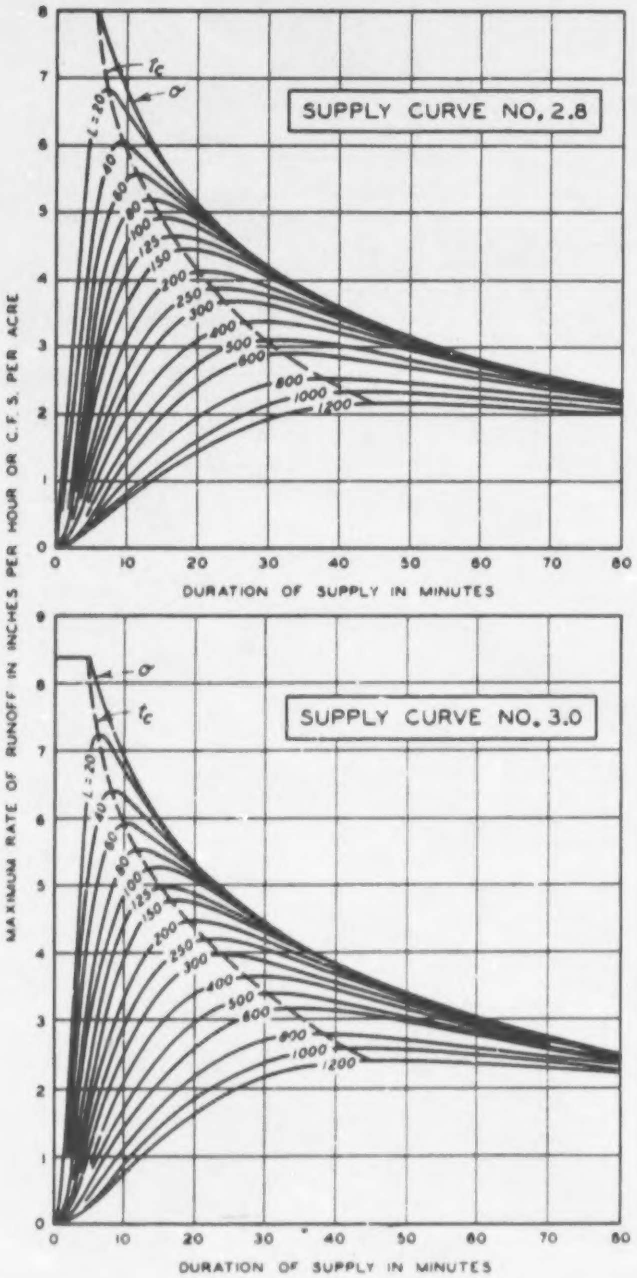


RATE OF RUNOFF CURVES

ANNEX A-1 For Use With Subcourse 359



RATE OF RUNOFF CURVES



RATE OF RUNOFF CURVES

ANNEX A-1 For Use With Subcourse 359

TABLE OF ROUGHNESS COEFFICIENTS (MANNING'S n)

A. OPEN CHANNELS--NONVEGETATED

Type of Lining	Manning's n Good Condition	Manning's n Poor Condition
1. Natural Streams		
a. Clean, straight bank, full state, no rifts or deep pools	.025	.033
b. Sames as (1) but some weeds and stones	.030	.040
c. Clean, winding, some pools and shoals	.033	.045
d. Same as (c), lower stages, more ineffective slope and sections	.040	.055
e. Same as (c), some weeds and stones	.035	.050
f. Same as (d), stony sections	.045	.060
g. Sluggish river reaches, weedy or with very deep pools	.050	.080
h. Very weedy reaches	.075	.150
i. Coarse gravel, weeds on banks	.025	.033
j. Fine, well-packed gravel	.020	
2. Earth		
a. Bare, straight, uniform	.017	.025
b. Dredged, rough bed	.025	.033
c. Winding sluggish	.023	.030
d. Earth bottom, rubble sides	.028	.035
3. Natural Rock		
a. Cuts smooth and uniform	.025	.035
b. Cuts jagged and irregular	.035	.045
4. Stone Work		
a. Dressed ashler	.013	.017
b. Dry rubble (riprap)	.025	.035
c. Cement rubble	.017	.030
5. Masonry		
a. Concrete finished	.011	.014
b. Concrete unfinished	.015	.020
c. Brick	.012	.017
6. Wood		
a. Planed	.010	.014
b. Unplaned	.011	.015
7. Metal		
a. Smooth	.011	.015
b. Corrugated	.022	.030

B. OPEN CHANNELS--VEGETATED

	Manning's n Trapezoidal Channels with Depth 1'	 Wide Shallow Channels or Swales with Depth 1'
8. Good Stand of Grass		
a. Longer than 24"	.09	.30
b. 10" to 24"	.06	.15
c. 6" to 10"	.04	.08
d. Shorter than 6"	.035	.06
If stand is only fair use value of n in next lower line e.g. for a fair stand 24" in trapezoidal channel use n = .06		

C. CLOSED CHANNELS

Type of Lining	Manning's n Good Condition	 Fair Condition
9. Pipe		
a. Concrete	.010	.016
b. Corrugated Metal (plain)	.021	.025
c. Corrugated Metal (paved invert)	.019	.023
d. Cast Iron (uncoated)	.011	.015
e. Vitrified clay	.011	.014
10. Box Culverts		
a. Concrete	.013	.015
b. Brick	.012	.017
c. Cemented Rubble	.017	.030

Table Of Maximum Mean Velocities Of Streams To Prevent Erosion

Material	Mean Velocity ft / sec
Very light pure sand of quicksand character	0.75-1.00
Very light loose sand	1.00-1.50
Coarse Sand	1.50-2.00
Light Sandy Soil	1.50-2.00
Average Sandy Soil	2.00-2.50
Sandy Loam	2.50-2.75
Average Loam, Alluvial Soil, Volcanic Ash Soil	2.75-3.00
Firm Loam	3.00-3.75
Clay Loam	3.00-3.75
Stiff Clay	4.00-5.00
Ordinary Gravel Soil	4.00-5.00
Coarse Gravel, Cobbles, Shingles	5.00-6.00
Cemented Gravel, Conglomerates	6.00-8.00
Tough Hardpan, Soft Slate	6.00-8.00
Soft Sedimentary Rock	6.00-8.00
Hard Rock	10.00-15.00

ANNEX A-3 For Use With Subcourse 359

TABLE OF ALLOWABLE VELOCITIES FOR ERODIBLE CHANNELS

Earth—No Vegetation*

	Type of Lining	Maximum Allowable Velocities		
		Clear Water ft/sec	Water Carrying Fine Silts (Collodial) ft/sec	Water Carrying Sand and Gravel ft/sec
a.	Fine Sand (noncolloidal)	1.5	2.5	1.5
b.	Sandy Loam (noncolloidal)	1.75	2.5	2.0
c.	Silt Loam (noncolloidal)	2.0	3.0	2.0
d.	Ordinary firm loam	2.5	3.5	2.25
e.	Volcanic ash	2.5	3.5	2.0
f.	Fine gravel	2.5	5.0	3.75
g.	Stiff clay (very colloidal)	3.75	5.0	3.0
h.	Graded, loam to cobbles (noncolloidal)	3.75	5.0	5.0
i.	Graded, silt to cobbles (colloidal)	4.0	5.5	5.0
j.	Alluvial silts (noncolloidal)	2.0	3.5	2.0
k.	Alluvial silts (colloidal)	3.75	5.0	3.0
l.	Coarse gravel (noncolloidal)	4.0	6.0	6.5
m.	Cobbles and shingles	5.0	5.5	6.5
n.	Shales and hard pans	6.0	6.0	5.0

*Recommended in 1926 by Special Committee on Irrigation Research ASCE

TABLE OF ALLOWABLE VELOCITIES FOR ERODIBLE LININGS

Earth with Vegetative Cover

Type of Cover	Slope Range %	Easily Eroded Soils ft/sec	Erosion Resistant Soils ft/sec
a. Bermuda grass sod	0-5	6	8
	5-10	5	7
	10+	4	6
b. Sod-forming grass such as:	0-5	5	7
Kentucky Blue grass	5-10	4	6
Buffalo grass	10+	3	5
Smooth Brome			
Red Top			
Blue Gamma			
c. Grass mixture. This is not recommended for use on slopes steeper than 10%	0-5	4	5
	5-10	3	4
d. Bunch grasses, vines and similar open cover such as:	0-5	2.5	3.5
Lespedeza	Not recommeded for use on slopes steeper than 5%		
Weeping Lovegrass			
Ischaemum (Yellow Bluestem)			
Kudzu			
Crabgrass			
Sudan grass			
Annuals (for temporary use)			

ANNEX A-3 For Use With Subcourse 359

ANNEX A-4 For Use With Subcourse 359

CAPACITY OF CULVERTS WITH FREE OUTLET, CMP

Water-Surface at Inlet same Elevation as Top of Pipe, and Outlet Unsubmerged
Values are in cubic feet per second. n = .024

Slope in %	Diameter of Pipe, in Inches										
	V fps	12	18	24	30	36	42	48	60	72	V fps
0.4	2	1.3	3.9	8.4	15	25	37	53	96	160	7
0.6	3	1.6	4.8	10	18	30	45	64	120	190	8
0.8		1.8	5.4	12	21	34	50	72	130	210	9
1.0		2.0	5.9	13	22	36	54	77	140	220	10
1.2	4	2.2	6.4	13	24	38	57	80	$\underline{150}$	$\underline{230}$	11
1.4		2.3	6.6	14	25	39	$\underline{59}$	82	150	230	
1.6		2.4	6.8	14	25	$\underline{40}$	59	$\underline{83}$	150	230	
1.8		2.5	7.0	14	$\underline{26}$	40	59	83			
2.0		2.5	7.0	$\underline{15}$	26	40					
2.2	5	$\underline{2.6}$	$\underline{7.1}$	15							
2.4		2.6	7.1								
2.6		2.6									
2.8	6	2.6									

NOTES:
1. Underlined values for Q indicate critical slope for the respective pipe.
2. The stairs indicate velocity of discharge in fps.

CAPACITY OF CULVERTS WITH FREE OUTLET, CONCRETE PIPE

Water-Surface at Inlet same Elevation as Top of Pipe, and Outlet Unsubmerged
Values are in cubic feet per second. n = .013

Slope in %	Diameter of Pipe, in Inches										
	V_{fps}	12	18	24	30	36	42	48	60	72	V_{fps}
.4	4	2.3	6.6	14	25	39	58	82	$\underline{150}$	$\underline{230}$	11
.6		2.5	$\underline{7.1}$	$\underline{15}$	$\underline{26}$	$\underline{40}$	$\underline{59}$	$\underline{83}$	150	230	12
.8	5	$\underline{2.6}$	7.1	15	26	40	59	83			
1.0		2.6									
		V_{fps}	6	7	8		9	10	11	V_{fps}	

NOTES: 1. Underlined values for Q indicate critical slope for the respective pipe.

2. The stairs indicate velocity of discharge in fps.

ANNEX A-5 For Use With Subcouse 359

PIPE COVER REQUIREMENTS FOR AIRFIELDS (IN FEET)

(Data Prepared by the U. S. Engineers, Office of the Chief of Engineers)

TYPE OF PIPE	30,000 LB PLANE						60,000 LB PLANE						120,000 LB PLANE						300,000 LB PLANE					
(Pipe Diameter in Inches)	6	12	24	36	48	60	6	12	24	36	48	60	6	12	24	36	48	60	6	12	24	36	48	60
Clay Sewer Pipe	1.5	3.0	3.0	3.5			3.0						4.0						7.0					
Clay Culvert Pipe (AASHO)		1.5	1.5	2.0				3.0	3.5	3.5				3.5	4.5	4.5								
Concrete Sewer Pipe	1.5	2.5	3.0				3.0	4.0					4.0						6.0					
Reinforced Concrete Sewer Pipe		2.0	3.0	3.5	4.0	4.0		3.5						4.5										
Reinforced Concrete Culvert Pipe		1.5	2.0	2.0	2.0	2.0		2.5	3.0	3.5	3.5	3.5		3.0	4.0	4.5				4.0	6.0	7.0	9.0	10.0
Reinforced Concrete Culvert Pipe (Extra Strength)			1.0	1.0	1.0	1.0			2.5	2.5	2.5	2.5			3.0	3.5	3.5	3.5		4.0	5.0	6.0	6.0	7.0
Corrugated Metal Pipe - 18 Gage	1.0						1.5	2.0					2.0						3.0					
Corrugated Metal Pipe - 16 Gage		1.0	1.5				1.0	2.0	3.0				1.5	2.5	4.0				2.0	3.0	6.0			
Corrugated Metal Pipe - 14 Gage			1.0	2.0				1.5	2.5	3.5				2.0	3.0	4.0				2.5	5.0	7.0		
Corrugated Metal Pipe - 12 Gage				1.0	2.0				1.5	2.5	3.5			1.5	2.5	3.5	4.0				4.0	6.0	7.0	
Corrugated Metal Pipe - 10 Gage					1.0	1.5				2.0	2.5	3.0			2.0	3.0	3.5	4.0			3.5	5.5	6.5	7.0
Corrugated Metal Pipe - 8 Gage						1.0					2.0	2.5				2.5	3.0	3.5			3.0	5.0	6.0	6.5

NOTES: 1. Pipe to conform to ASTM Specifications except as noted. Pipe produced by certain manufacturers exceeds strength established by ASTM standards. When proof of extra strength is submitted the minimum cover may be varied accordingly.

2. Cover for pipes within landing or taxiway strips or similar traffic areas shall be provided in accordance with above table except as provided for rigid pavements in Note 3 below.

3. Pipe placed under concrete airfield pavements shall have a minimum cover measured below the slab of 1.0 foot for plane loads up to and including 120,000 lbs. and 2.0 feet for 300,000-lb. plane loads, except that minimum cover below thickened edges may be reduced to 0.5 foot for 120,000-lb plane loads or less, and to 1.0 foot for 300,000-lb. plane loads.

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Recommended gages for nestable corrugated pipe

Diam. in inches	Waterway area (sq. ft.)	Fills up to 8 ft.	Fills up to 16 ft.	20-ft. fill	25-ft. fill	30-ft. fill	35-ft. fill	40-ft. fill
8	.35	16	16	16	16	16	16	16
10	.55	16	16	16	16	16	16	16
12	.79	16	16	16	16	16	16	16
15	1.23	16	16	16	16	16	16	16
18	1.77	16	16	16	16	16	16	16
21	2.41	16	16	16	16	16	16	16
24	3.14	16	16	16	16	14	14	14
30	4.91	14	14	14	14	14	12	12
36	7.07	14	14	14	12	12	12	10
42	9.62	14	14	12	12	10	10	8
48	12.57	12	12	12	10	8	8	8
54	15.90	12	12	10	8	8	8	8
60	19.64	12	10	8	8	8	8	8
66	23.76	10	10	8	8	8	8	
72	28.27	10	10	8	8	8	Must be designed for these fill heights and others above 40 ft.	
78	33.18	8	8	8	8			
84	38.49	8	8	8	8			

Note. Culverts below heavy line should be strutted during installation.

Strut spacing using 4- by 4-inch timbers with compression caps

Diameter in inches	Length of strut in inches	Fill heights in feet			
		1-5	5-10	10-20	20-30
		Spacing of struts in feet			
48	37.5	6	6	6	6
54	43.6	6	6	6	6
60	49.8	6	6	6	6
66	56.0	6	6	6	6
72	62.2	6	6	6	5

ANNEX A-6 For Use With Subcouse 359

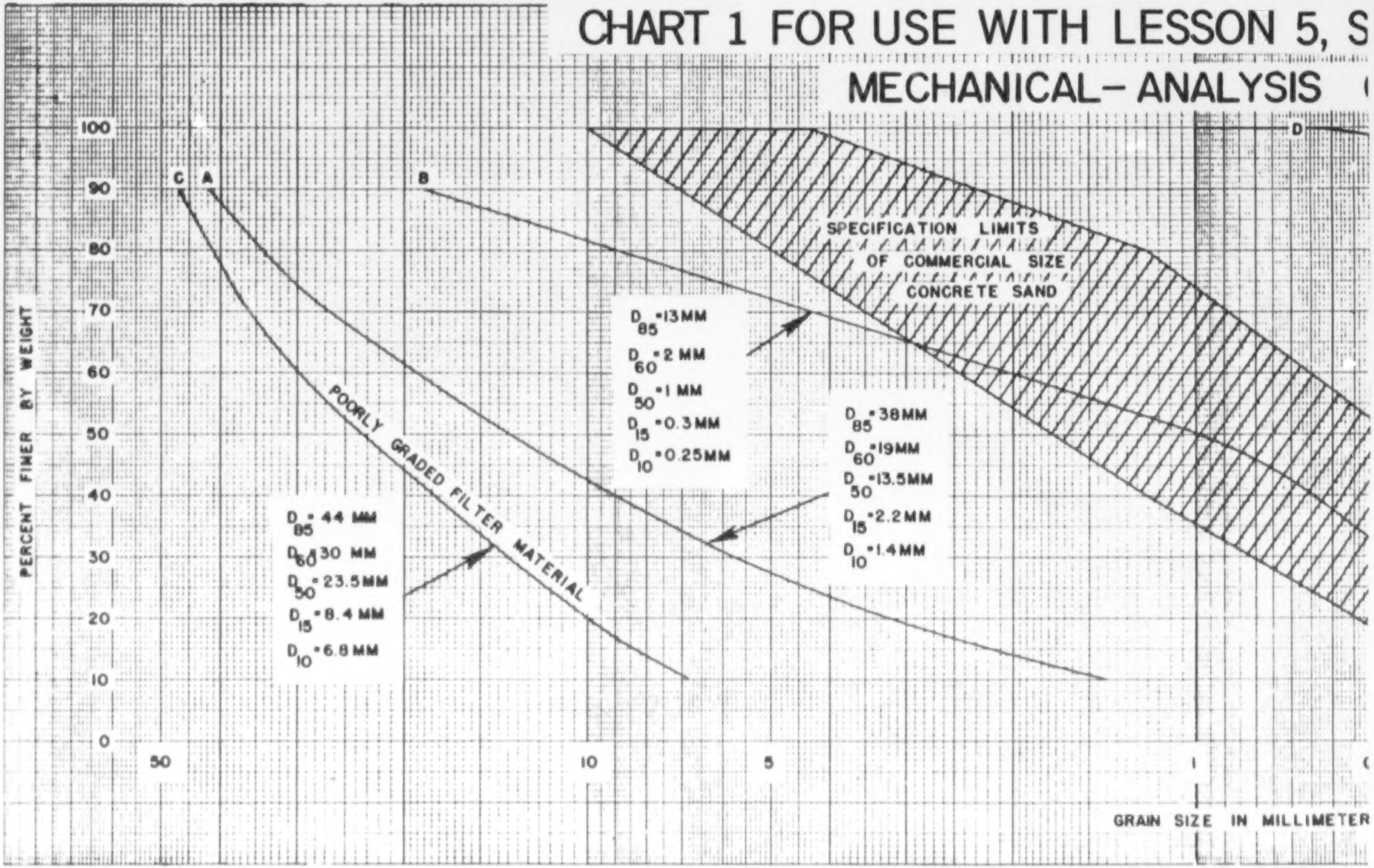
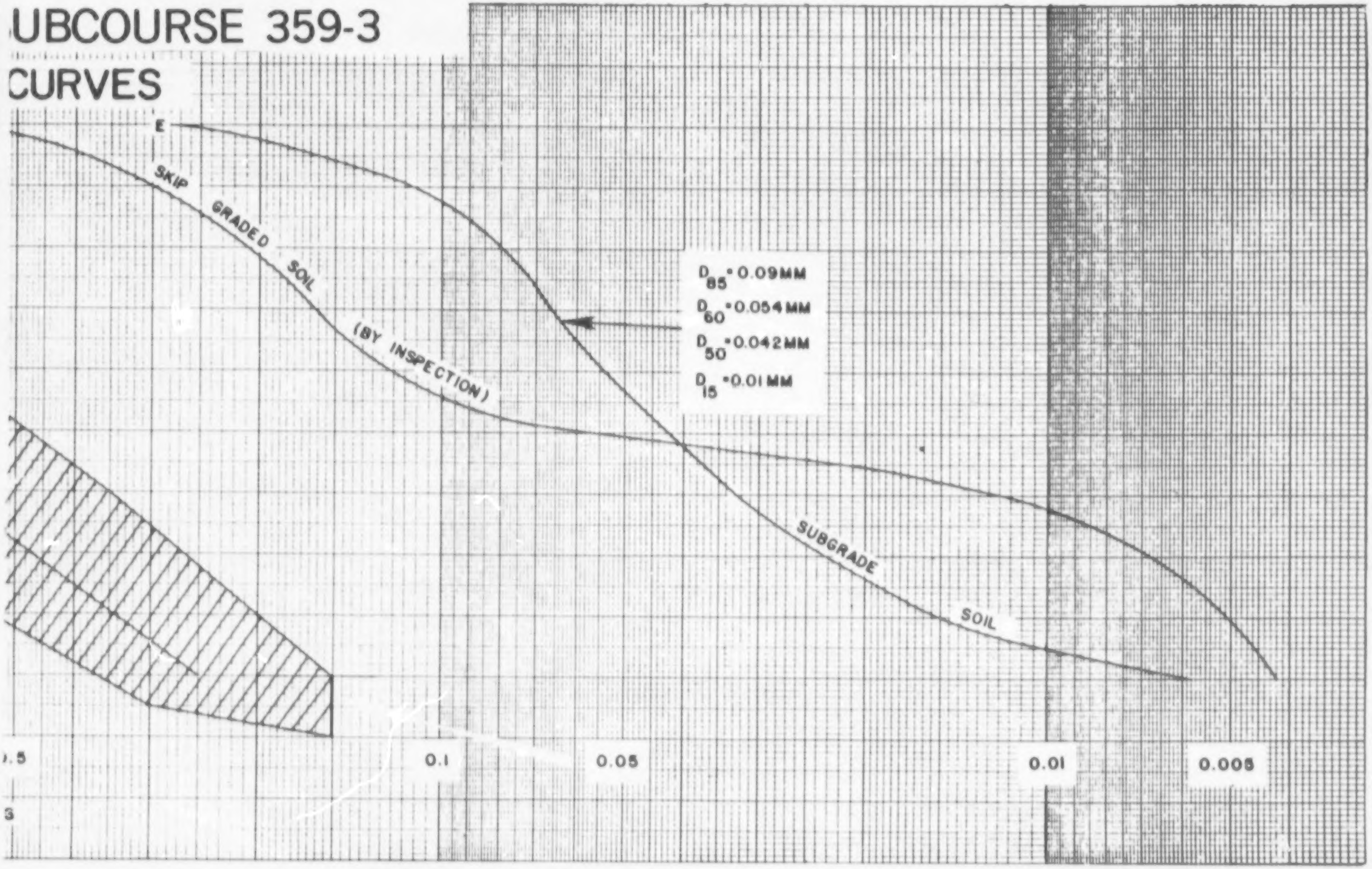


CHART 1 FOR USE WITH LESSON 5, S

MECHANICAL- ANALYSIS (

CHART I (continued)



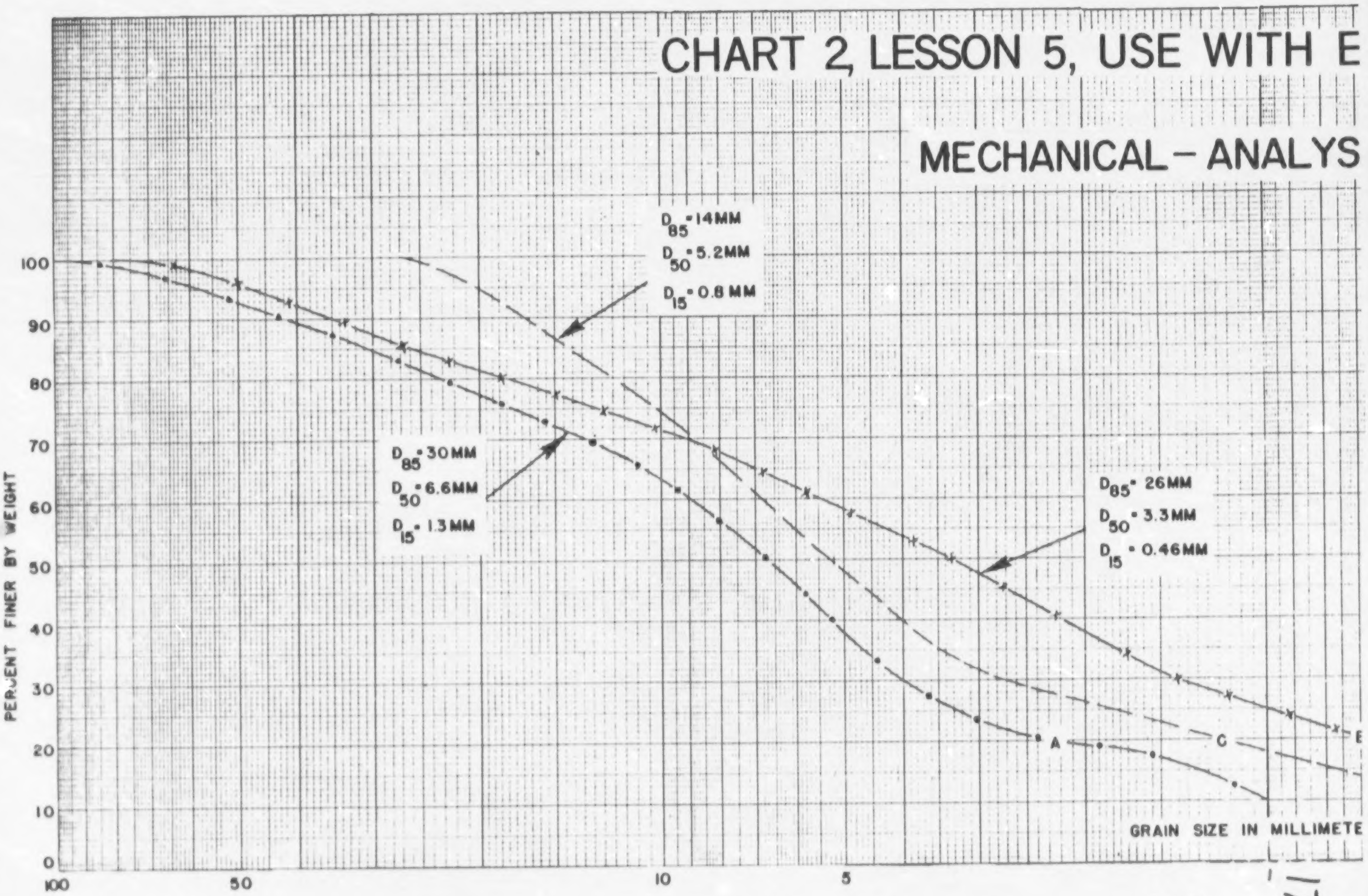
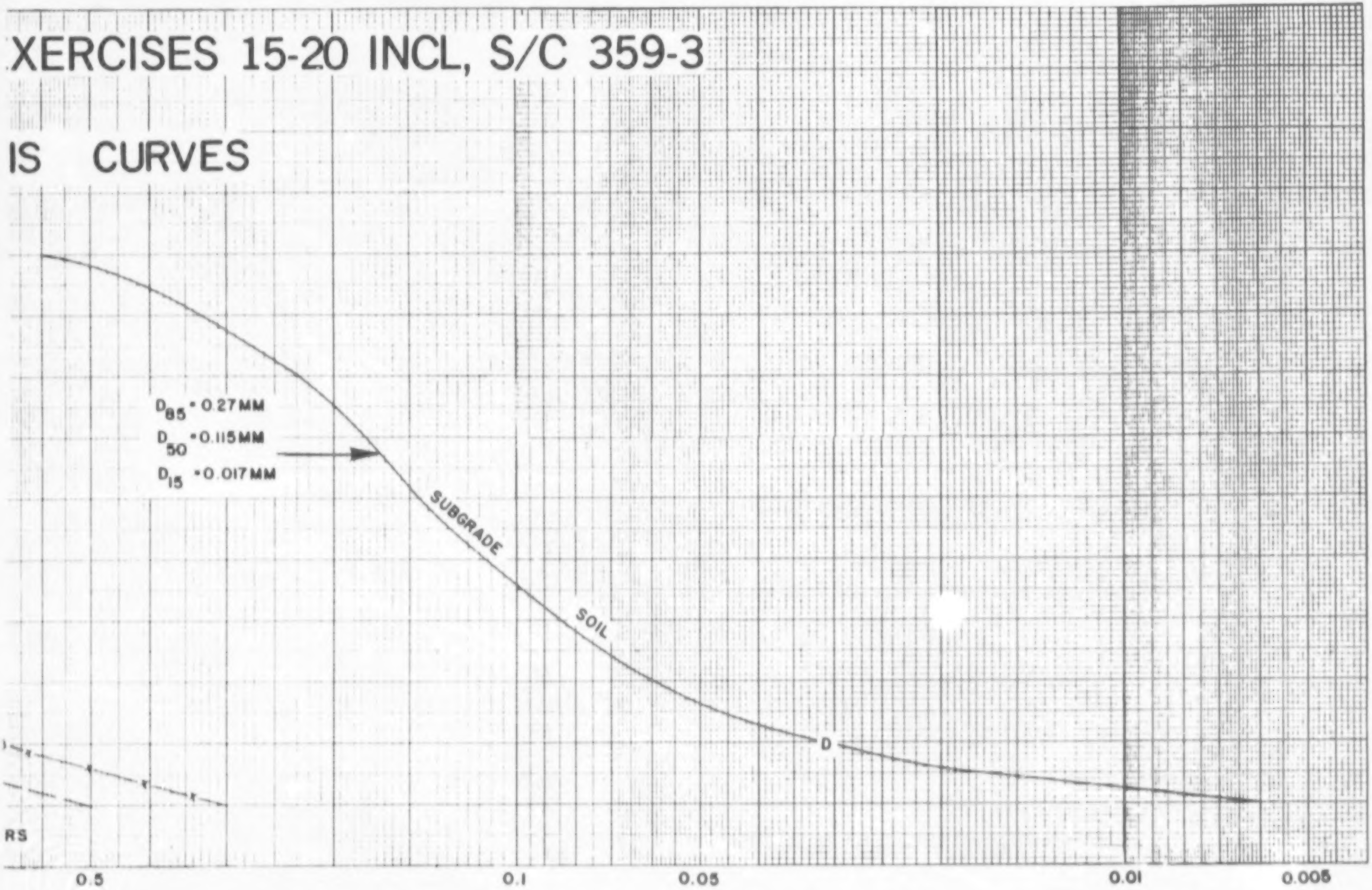


CHART 2, LESSON 5, USE WITH E

MECHANICAL - ANALYS

CHART 2 (continued)



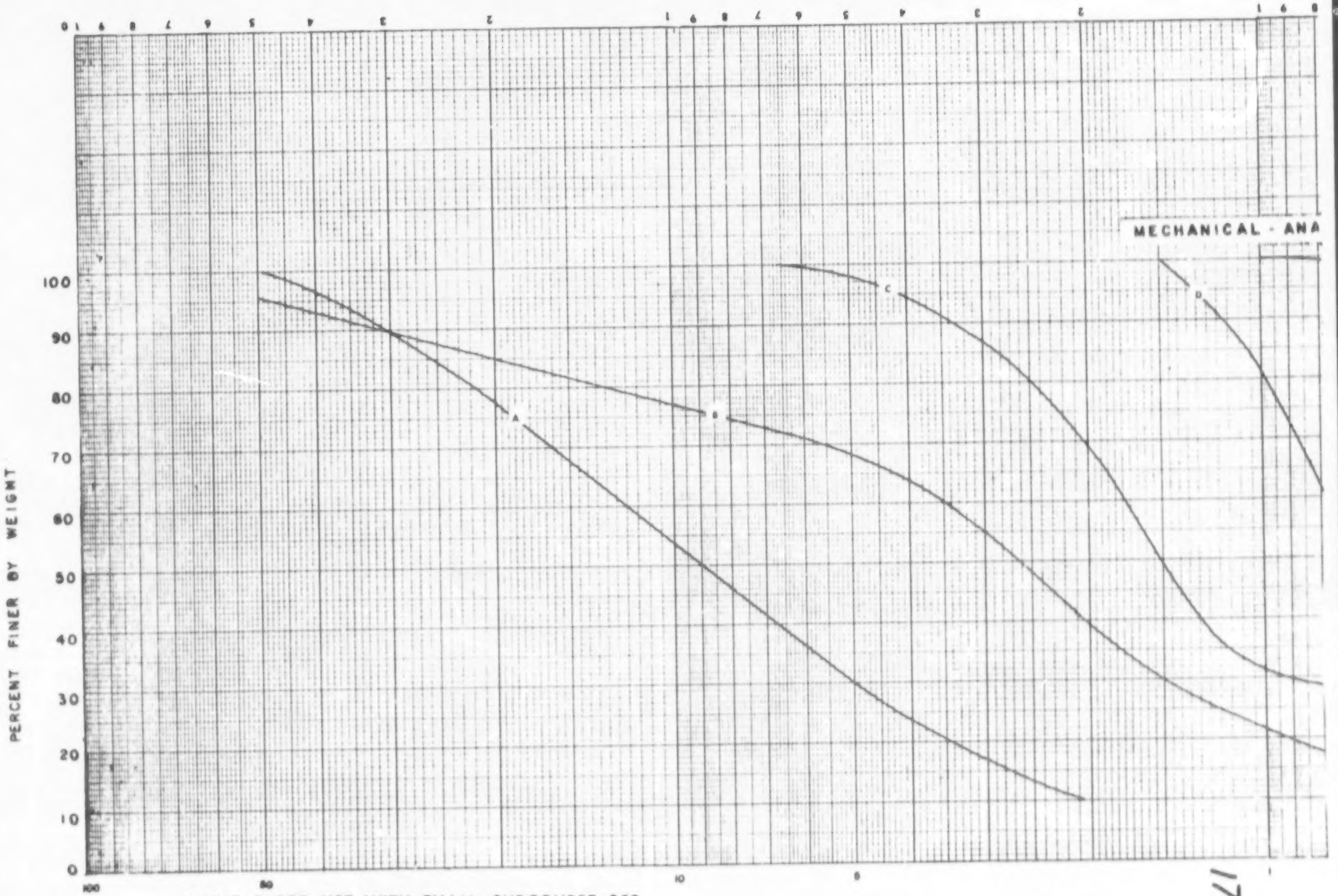


CHART 3 FOR USE WITH EXAM, SUBCOURSE 359

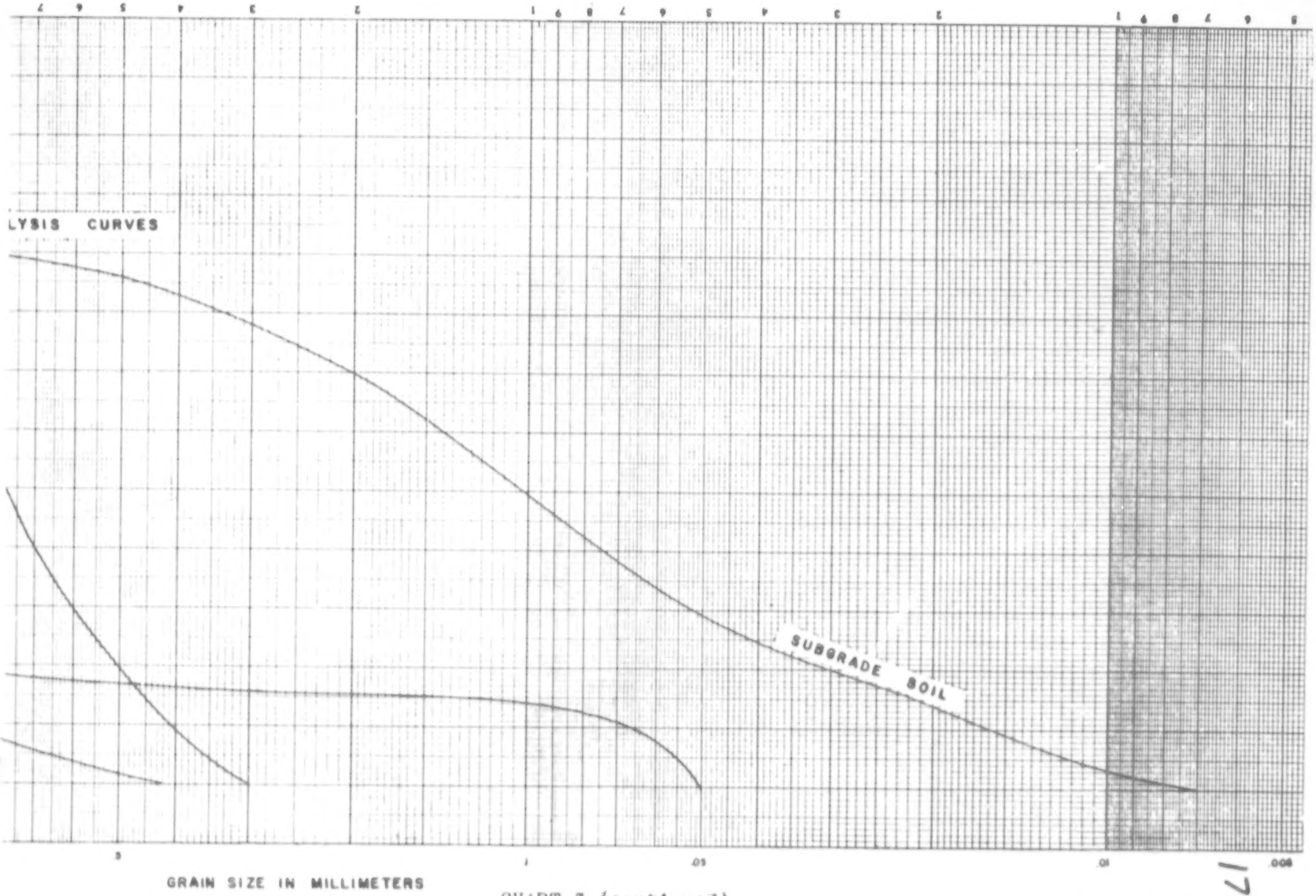


CHART 3 (continued)

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